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PERFORMANCE EVALUATION OF NEW JERSEY'S PORTABLE CONCRETE BARRIER WITH A BOX-BEAM STIFFENED CONFIGURATION AND GROUTED TOES – TEST NO. NJPCB-5

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16. Abstract

This report documents a full-scale crash test conducted in support of a study to investigate the performance of New Jersey Department of Transportation's (NJDOT's) Precast Concrete Curb, Construction Barrier, which will be referred as portable concrete barrier (PCB) in various configurations. This represents the fifth system as part of this study.

The primary objective of this research effort was to evaluate the safety performance of the NJDOT PCB, Type 4 (Alternative B) with a box-beam stiffened configuration and grouted toes, corresponding connection type B in the 2015 NJDOT *Roadway Design Manual*. The system utilized 6-in. × 6-in. × $^{3}/_{16}$-in. (152-mm × 152-mm × 5-mm) box beam sections placed across all nine joints. Barrier nos. 1 and 10 were anchored to the concrete tarmac through the pin anchor recesses with nine 1-in. (25-mm) diameter by 15-in. (381-mm) long ASTM A36 steel pins inserted into 1¼-in. (32-mm) diameter drilled holes in the concrete tarmac. Non-shrink grout wedges were placed at the toe of each barrier segment in every joint between adjacent barrier segments. The barrier was evaluated according to the Test Level 3 (TL-3) criteria set forth in the *Manual for Assessing Safety Hardware, Second Edition* (MASH 2016). The research study included one full-scale vehicle crash test with a 2270P pickup truck. Following the successful redirection of the pickup truck, the safety performance of the system was determined to be acceptable according to the test designation no. 3-11 evaluation criteria specified in MASH 2016. The 1100C small car crash test was deemed unnecessary due to previous testing. The barrier successfully met MASH 2016 TL-3 criteria. This report is the fifth of nine documents in the nine-test series.

17. Document Analysis/Descriptors Highway Safety, Roadside Appurtenances, Crash Test, Compliance Test, MASH 2016, Longitudinal Barrier, Portable Concrete Barrier, PCB, Grout Wedges, Pinned, Barrier Curb, and Box-Beam Stiffeners		18. Availability Statement No restrictions. Document available from: National Technical Information Services, Springfield, Virginia 22161	
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UNCERTAINTY OF MEASUREMENT STATEMENT

The Midwest Roadside Safety Facility (MwRSF) has determined the uncertainty of measurements for several parameters involved in standard full-scale crash testing and non-standard testing of roadside safety features. Information regarding the uncertainty of measurements for critical parameters is available upon request by the sponsor and the Federal Highway Administration.

INDEPENDENT APPROVING AUTHORITY

The Independent Approving Authority (IAA) for the data contained herein Dr. Jennifer Schmidt, Research Assistant Professor.

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1 INTRODUCTION

1.1 Background

The New Jersey Department of Transportation (NJDOT) currently uses a New Jersey shape, Precast Concrete Curb, Concrete Barrier, which will be referred to as portable concrete barrier (PCB), with a vertical, I-beam connection pin to attach barriers end to end within their work zones and construction areas. The 2013 NJDOT *Roadway Design Manual* [1] provided guidance on allowable barrier deflections for various classes of PCB joint treatments, as shown in Table 1. The current 2015 NJDOT *Roadway Design Manual* [2] provides guidance on allowable deflections for various connection types, as shown in Table 2.

Table 1. 2013 NJDOT Roadway Design Manual PCB Guidance [1]

Joint Class	Use	Joint Treatment
A	Allowable movement over 16 to 24 inches	Connection Key only
B	Allowable movement over 11 to 16 inches	Connection Key and grout in every joint
C	Allowable movement of 11 inches	Connection Key and grout in every joint and pin every other unit. In units to be anchored, pin should be required in every recess
D	No allowable movement (i.e., bridge parapet)	Connection Key and grout in every joint and bolt every anchor pocket hole in every unit

Table 2. Current 2015 NJDOT Roadway Design Manual PCB Guidance [2]

Connection Type	Use	Joint Treatment*
A	Maximum allowable deflection of 41 inches	Connection Key and barrier end sections fully pinned
B	Maximum allowable deflection of 28 inches (Cannot be used with traffic on both sides of the barrier.)	Connection Key, 6” by 6” box beam, and barrier end sections fully pinned
C	Maximum allowable deflection of 11 inches	Connection Key, construction side of all sections pinned, and barrier end sections fully pinned

* Barrier end sections fully pinned – first and last barrier segments of the entire run regardless of connection type have pins in every anchor recess on both sides.

The guidance provided in both the 2013 and 2015 *Roadway Design Manual* was based on test data obtained from previous testing standards, which needs to be updated to be consistent with current crash testing standards and a changing vehicle fleet. Crash testing of other PCB systems under the Test Level 3 (TL-3) criteria of the *Manual for Assessing Safety Hardware, Second Edition* (MASH 2016) [3] has indicated that dynamic barrier deflections can increase significantly when compared to dynamic deflections based on older crash test data. Thus, a need exists to investigate the performance of the NJDOT PCB system in various configurations in order to provide updated design guidance. The NJDOT PCB standard plans are shown in Appendix A.

1.2 Objective

The objective of this research effort was to evaluate the safety performance of NJDOT's PCB, Type 4 (Alternative B) system with a box-beam stiffened, free-standing configuration and grouted toes, corresponding to connection type B in the 2015 NJDOT *Roadway Design Manual*. The system was to be evaluated according to the Test Level 3 (TL-3) criteria set forth in the *Manual for Assessing Safety Hardware, Second Edition* (MASH 2016) [3].

1.3 Scope

The research objective was achieved through completion of several tasks. One full-scale crash test was conducted on the PCB system according to MASH 2016 test designation no. 3-11. Next, the full-scale vehicle crash test results were analyzed, evaluated, and documented. Conclusions and recommendations were then made pertaining to the safety performance of the PCB system.

2 TEST REQUIREMENTS AND EVALUATION CRITERIA

2.1 Test Requirements

Longitudinal barriers, such as PCBs, must satisfy impact safety standards in order to be declared eligible for federal reimbursement by the Federal Highway Administration (FHWA) for use on the National Highway System (NHS). For new hardware, these safety standards consist of the guidelines and procedures published in MASH 2016 [3]. Note that there is no difference between MASH 2009 [4] and MASH 2016 for most longitudinal barriers, such as the PCB system tested in this project, except that additional occupant compartment deformation measurements are required by MASH 2016. According to TL-3 of MASH 2016, longitudinal barrier systems must be subjected to two full-scale vehicle crash tests, as summarized in Table 3. However, only the 2270P crash test was deemed necessary as other prior small car tests were used to support a decision to deem the 1100C crash test not critical.

Table 3. MASH 2016 TL-3 Crash Test Conditions for Longitudinal Barriers

Test Article	Test Designation No.	Test Vehicle	Vehicle Weight, lb (kg)	Impact Conditions		Evaluation Criteria [1]
				Speed, mph (km/h)	Angle, deg.	
Longitudinal Barrier	3-10	1100C	2,420 (1,100)	62 (100)	25	A,D,F,H,I
	3-11	2270P	5,000 (2,268)	62 (100)	25	A,D,F,H,I

[1] Evaluation criteria explained in Table 4.

In test no. 7069-3, a rigid, F-shape, concrete bridge rail was successfully impacted by a small car weighing 1,800 lb (816 kg) at 60.1 mph (96.7 km/h) and 21.4 degrees according to the American Association of State Highway and Transportation Officials (AASHTO) *Guide Specifications for Bridge Railings* [5-6]. In the same manner, test nos. CMB-5 through CMB-10, CMB-13, and 4798-1 showed that rigid, New Jersey, concrete safety shape barriers struck by small cars have been shown to meet safety performance standards [7-8]. In addition, in test no. 2214NJ-1, a rigid, New Jersey, ½-section, concrete safety shape barrier was impacted by a passenger car weighing 2,579 lb (1,170 kg) at 60.8 mph (97.8 km/h) and 26.1 degrees according to the TL-3 standards set forth in MASH 2009 [9]. Furthermore, temporary, New Jersey safety shape, concrete median barriers have experienced only slight barrier deflections when impacted by small cars and behave similarly to rigid barriers as seen in test no. 47 [10]. As such, the 1100C passenger car test was deemed not critical for testing and evaluating this PCB system.

It should be noted that the test matrix detailed herein represents the researchers' best engineering judgement with respect to the MASH 2016 safety requirements and their internal evaluation of critical tests necessary to evaluate the crashworthiness of the barrier system. However, the recent switch to new vehicle types as part of the implementation of the MASH 2016 criteria and the lack of experience and knowledge regarding the performance of the new vehicle types with certain types of hardware could result in unanticipated barrier performance. Thus, any tests within the evaluation matrix deemed non-critical may eventually need to be evaluated based on additional knowledge gained over time or revisions to the MASH 2016 criteria.

2.2 Evaluation Criteria

Evaluation criteria for full-scale vehicle crash testing are based on three appraisal areas: (1) structural adequacy; (2) occupant risk; and (3) vehicle trajectory after collision. Criteria for structural adequacy are intended to evaluate the ability of the PCB system to contain and redirect impacting vehicles. In addition, controlled lateral deflection of the test article is acceptable. Occupant risk evaluates the degree of hazard to occupants in the impacting vehicle. Post-impact vehicle trajectory is a measure of the potential of the vehicle to result in a secondary collision with other vehicles and/or fixed objects, thereby increasing the risk of injury to the occupants of the impacting vehicle and/or other vehicles. These evaluation criteria are summarized in Table 4 and defined in greater detail in MASH 2016. The full-scale vehicle crash test documented herein was conducted and reported in accordance with the procedures provided in MASH 2016.

In addition to the standard occupant risk measures, the Post-Impact Head Deceleration (PHD), the Theoretical Head Impact Velocity (THIV), and the Acceleration Severity Index (ASI) were determined and reported. Additional discussion on PHD, THIV and ASI is provided in MASH 2016.

Table 4. MASH 2016 Evaluation Criteria for Longitudinal Barrier

<table>
<tr><td>Structural Adequacy</td><td>A.</td><td colspan="3">Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td></tr>
<tr><td rowspan="10">Occupant Risk</td><td>D.</td><td colspan="3">Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH 2016.</td></tr>
<tr><td>F.</td><td colspan="3">The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td></tr>
<tr><td rowspan="4">H.</td><td colspan="3">Occupant Impact Velocity (OIV) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:</td></tr>
<tr><td colspan="3">Occupant Impact Velocity Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>30 ft/s
(9.1 m/s)</td><td>40 ft/s
(12.2 m/s)</td></tr>
<tr><td rowspan="4">I.</td><td colspan="3">The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:</td></tr>
<tr><td colspan="3">Occupant Ridedown Acceleration Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>15.0 g’s</td><td>20.49 g’s</td></tr>
</table>

3 DESIGN DETAILS

The test installation consisted of ten 20-ft (6.1-m) long NJDOT PCBs with a box-beam stiffened configuration and grouted toes, as shown in Figures 1 through 16. This system uses NJDOT barriers, Type 4 (Alternative B) with connection type B, as specified in the 2015 NJDOT *Roadway Design Manual*. Photographs of the test installation are shown in Figures 17 through 19. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix B.

The concrete mix for the barrier sections required a minimum 28-day compressive strength of 3,700 psi (25.5 MPa). A minimum concrete cover of 1½ in. (38 mm) was used along all rebar in the barrier. All of the steel reinforcement in the barrier was ASTM A615 Grade 60 rebar and consisted of four No. 6 longitudinal bars, eight No. 4 bars for the vertical stirrups, four No. 6 lateral bars, and nine No. 4 bars for the anchor hole reinforcement loops. The section reinforcement details are shown in Figures 5 and 6.

The barrier sections used a connection key, as shown in Figures 9 through 13, 18, and 19. The connection key assembly consisted of ½-in. (13-mm) thick ASTM A36 steel plates welded together to form the key shape. A connection socket was configured at each end of the barrier section, as shown in Figures 2, 18, and 19. The connection socket consisted of three ASTM A36 steel plates welded on the sides of ASTM A500 Grade B or C steel tube, as shown in Figures 9 and 10. The connection key was inserted into the steel tubes of two adjoining PCBs to form the connection, as shown in Figure 13.

Barrier nos. 1 and 10 were anchored to the concrete tarmac through the pin anchor recesses with nine 1-in. (25-mm) diameter by 15-in. (381-mm) long, ASTM A36 steel pins inserted into 1¼-in. (32-mm) diameter drilled holes in the concrete tarmac, as shown in Figures 1 and 14. The steel pins were embedded to a depth of 5 in. (127 mm), as shown in Figure 1. During installation, the barrier segments were pulled in a direction parallel to their longitudinal axes, and slack was removed from all joints. After slack was removed from all the joints, 1¼-in. (32-mm) diameter holes were drilled for pin anchors at pin recess locations. Five samples of concrete tarmac were tested from five different locations of MwRSF's Outdoor Test Site. The concrete tarmac had a compressive strength between 5,970 and 7,040 psi (41.2 and 48.5 MPa), as shown in Appendix C. Non-shrink grout wedges were placed at the toe of each barrier segment in every joint between adjacent barrier segments on both traffic and back sides, as shown in Figures 1, 2, and 19. The grout wedges consisted of a grout mix with a minimum 1-day compressive strength of 1,000 psi (6.9 MPa).

The nine joints between barrier nos. 1 through 10 were stiffened with a box-beam section, as shown in Figures 3, 7, 8, 17, and 18. Each box-beam stiffener was a 12-ft (3.7-mm) long, 6-in. × 6-in. × $^{3}/_{16}$-in. (152-mm × 152-mm × 5-mm) ASTM A500 Grade C box beam. Two ⅞-in. (22-mm) diameter holes were drilled through each barrier near the ends, as shown in Figure 7. The box-beam stiffeners were connected to the barriers with ¾-in. (19-mm) diameter by 17-in. (432-mm) long ASTM A307 Grade A bolts without square necks and ¾-in. (19-mm) diameter ASTM A563A nuts, as shown in Figure 8. A ¾-in. (19-mm) diameter ASTM F844 fender washer was placed between the barrier and the bolt head on the traffic side. An 8-in. × 8-in. × ½-in. (203-mm × 203-mm × 13-mm) ASTM A36 steel plate was placed between the nut and the box-beam section on the back side, as shown in Figure 8.

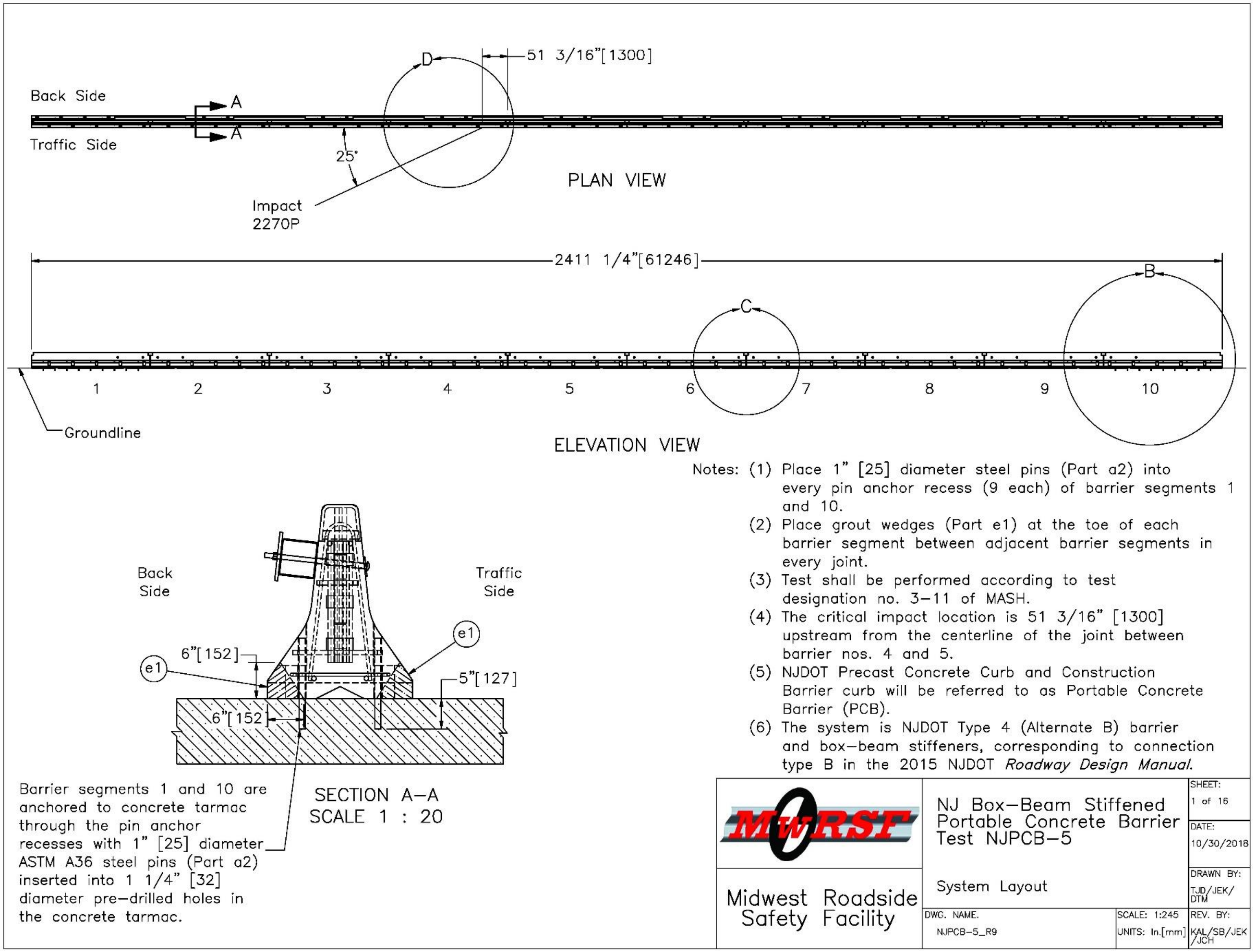


Figure 1. Test Installation Layout, Test No. NJPCB-5

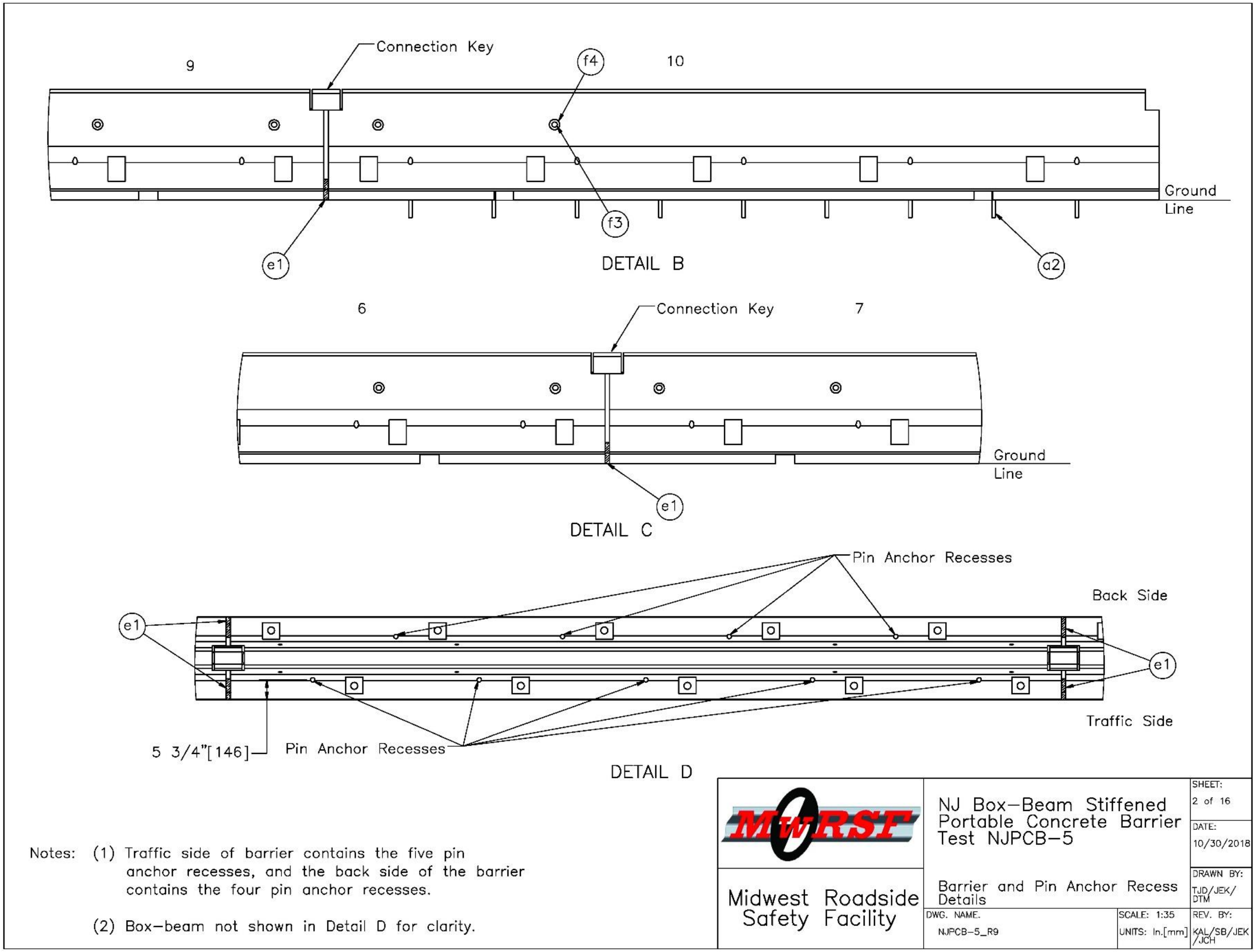
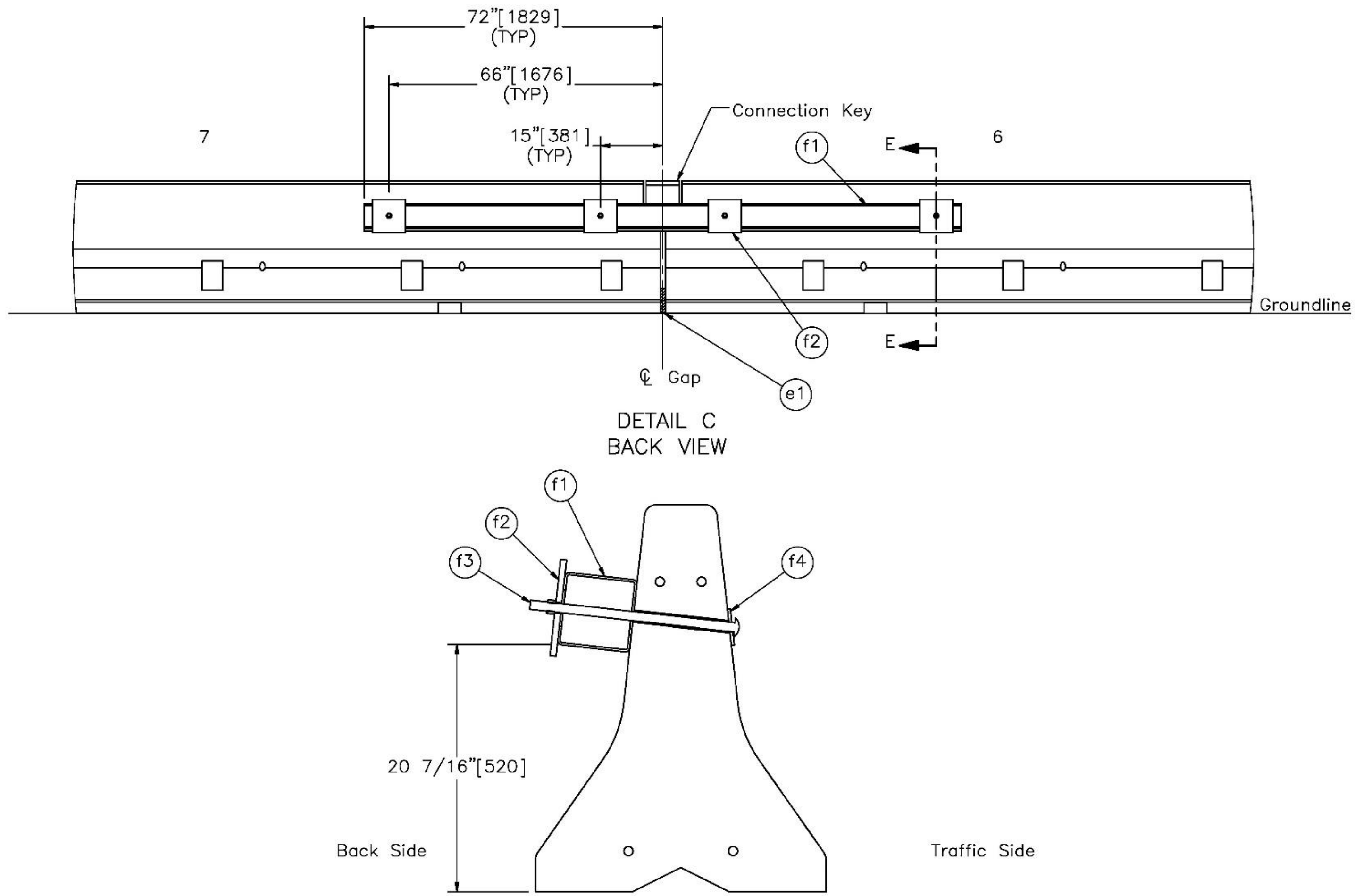


Figure 2. PCB Pin Anchor Details, Test No. NJPCB-5



Notes: (1) The box-beam section (Part f1) will be attached using carriage bolts without square neck (Part f3) with the smooth end on the traffic side of the barrier.
(2) Length of the box-beam (Part f1) shall be 12' [3658] continuous. Splices are not permitted.
(3) Fender washers (Part f4) to be 3" [76] nominal OD.

Midwest Roadside Safety Facility	NJ Box-Beam Stiffened Portable Concrete Barrier Test NJPCB-5	SHEET: 3 of 16
		DATE: 10/30/2018
	Box-Beam Details	DRAWN BY: TJD/JEK/DTM
	DWG. NAME. NJPCB-5_R9 — SCALE: 1:35 — UNITS: In.[mm]	REV. BY: KAL/SB/JEK/JCH

Figure 3. PCB Box-Beam Stiffener Details, Test No. NJPCB-5

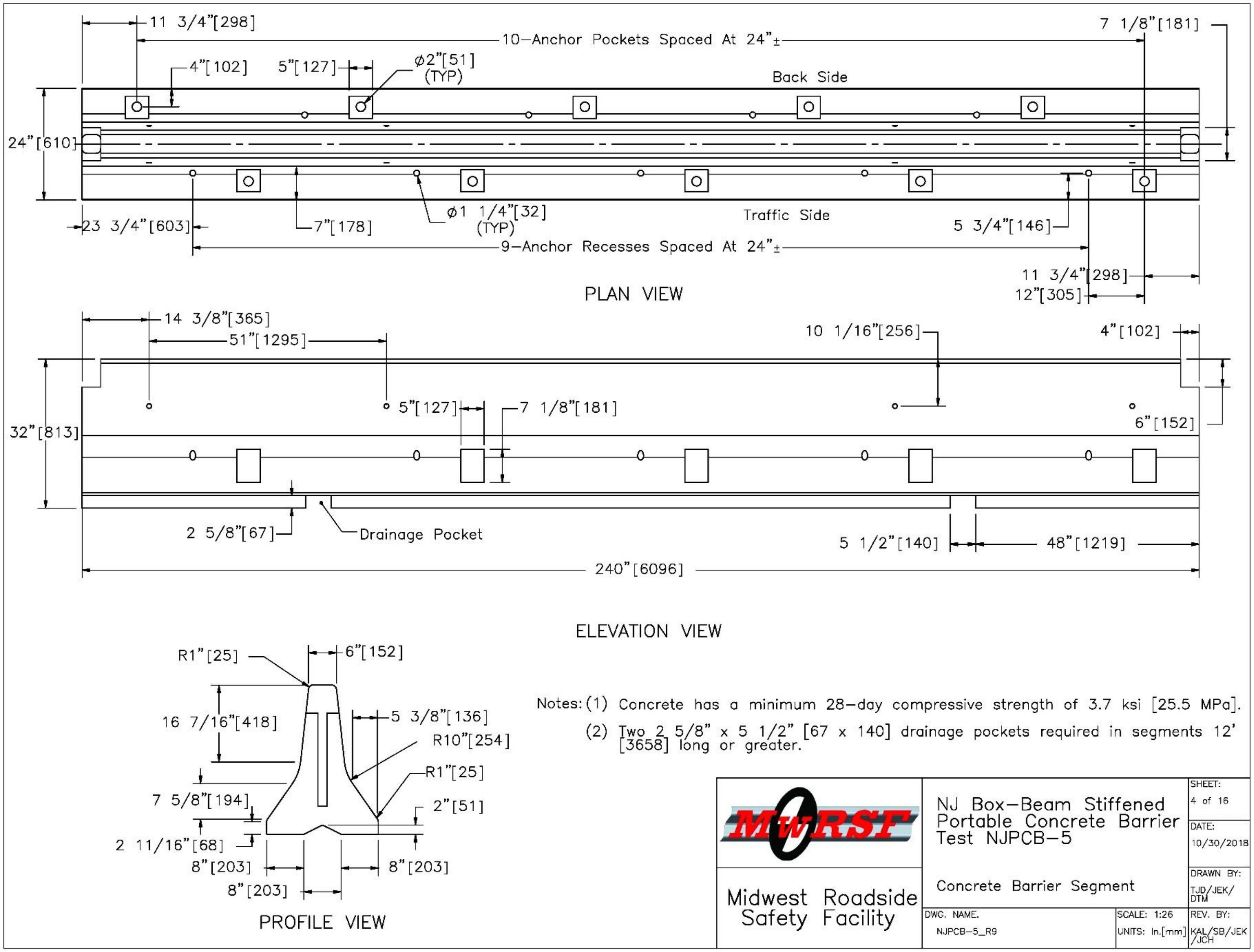


Figure 4. PCB Details, Test No. NJPCB-5

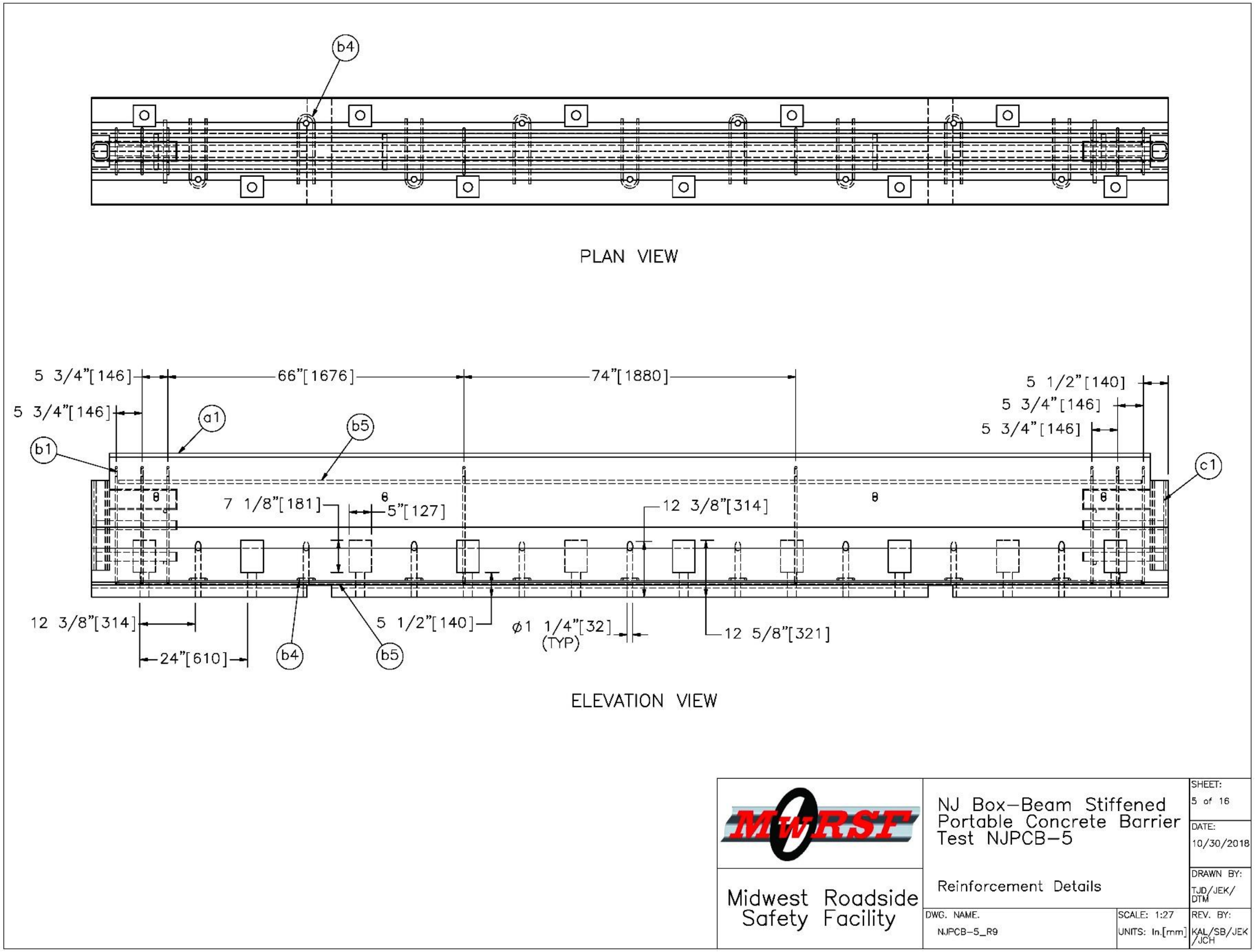


Figure 5. PCB Reinforcement Details, Test No. NJPCB-5

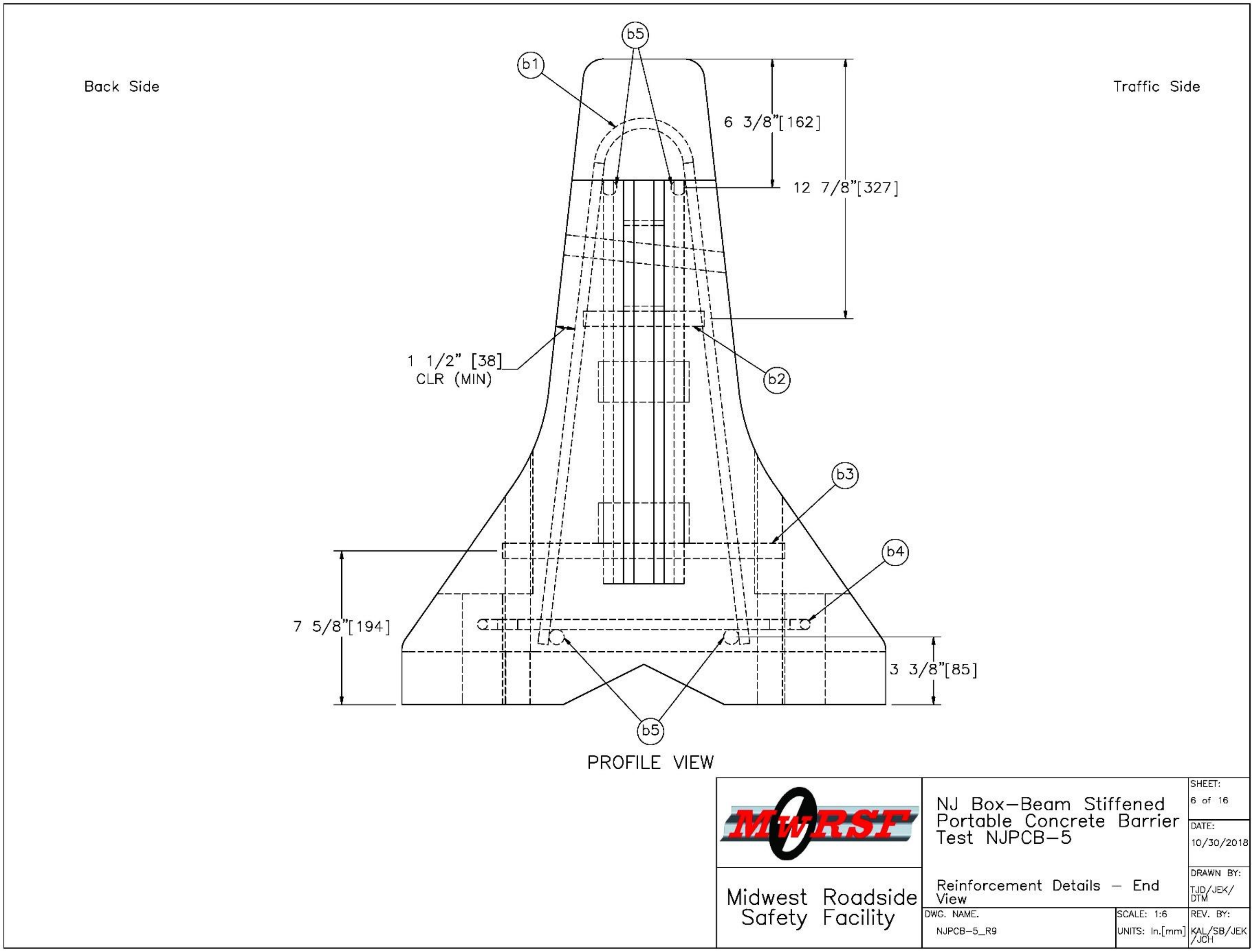


Figure 6. PCB Reinforcement Details – End View, Test No. NJPCB-5

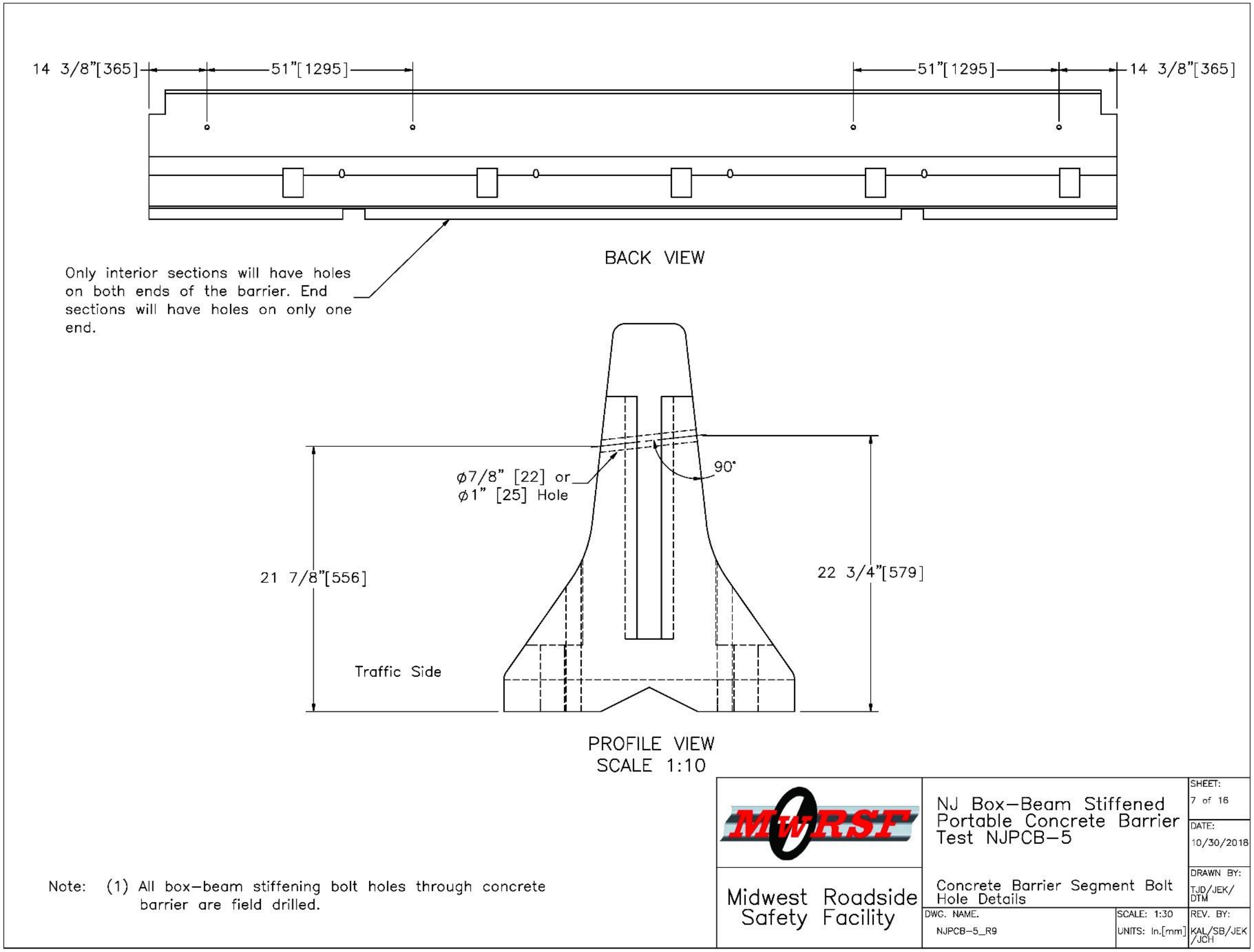


Figure 7. PCB Bolt Holes for Box-Beam Stiffeners, Test No. NJPCB-5

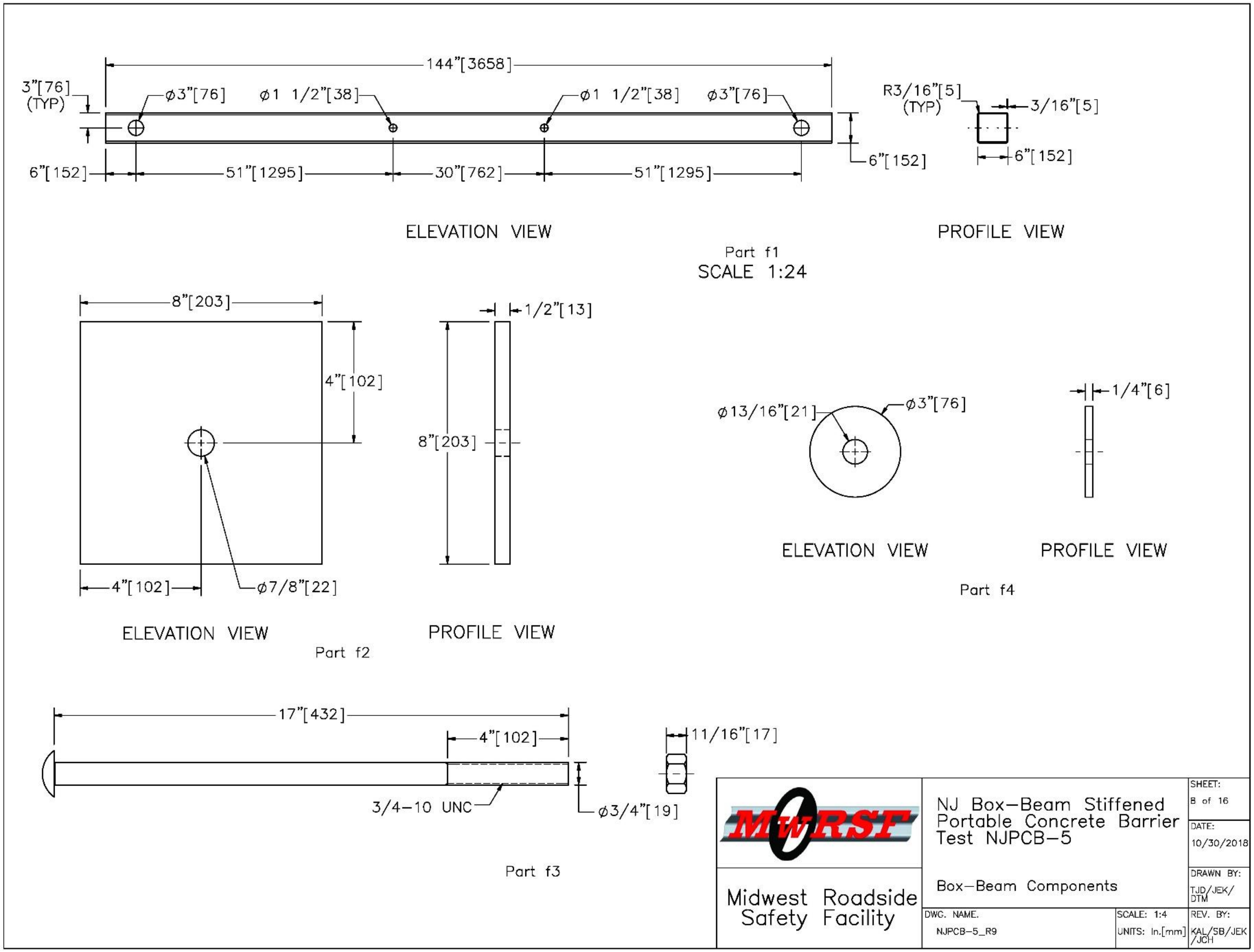


Figure 8. Box-Beam Stiffener Component Details, Test No. NJPCB-5

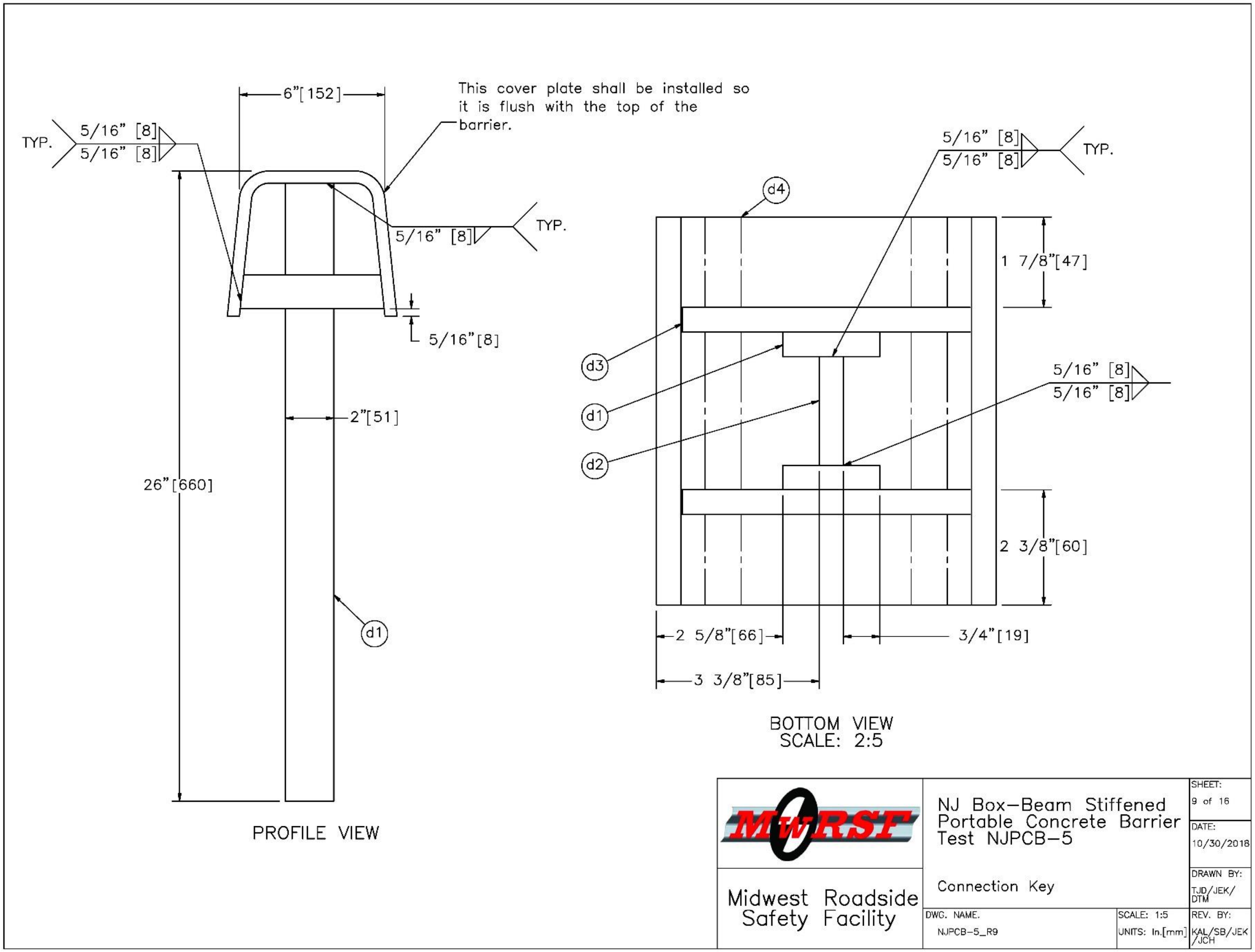


Figure 9. Connection Key Assembly Details, Test No. NJPCB-5

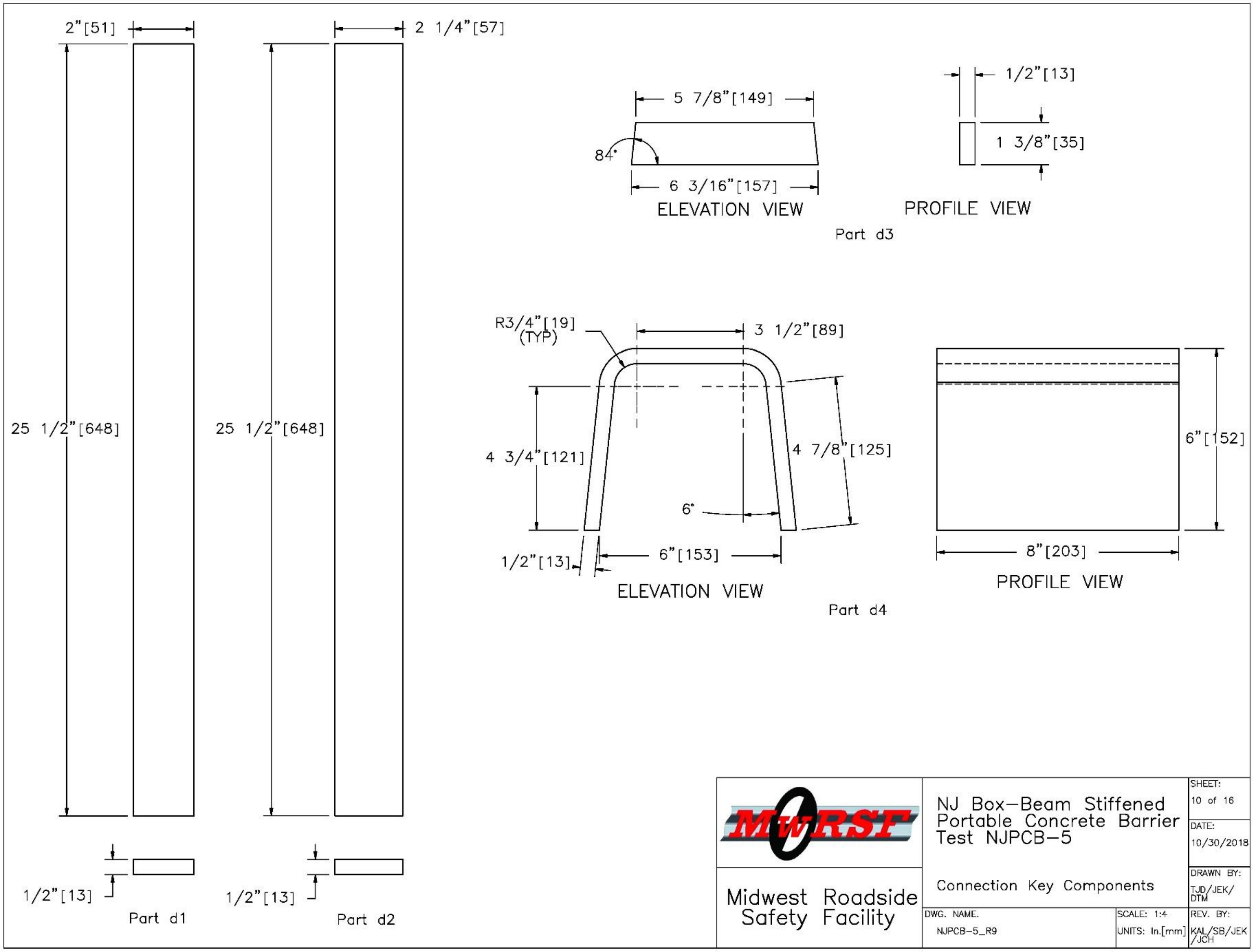


Figure 10. Connection Key Component Details, Test No. NJPCB-5

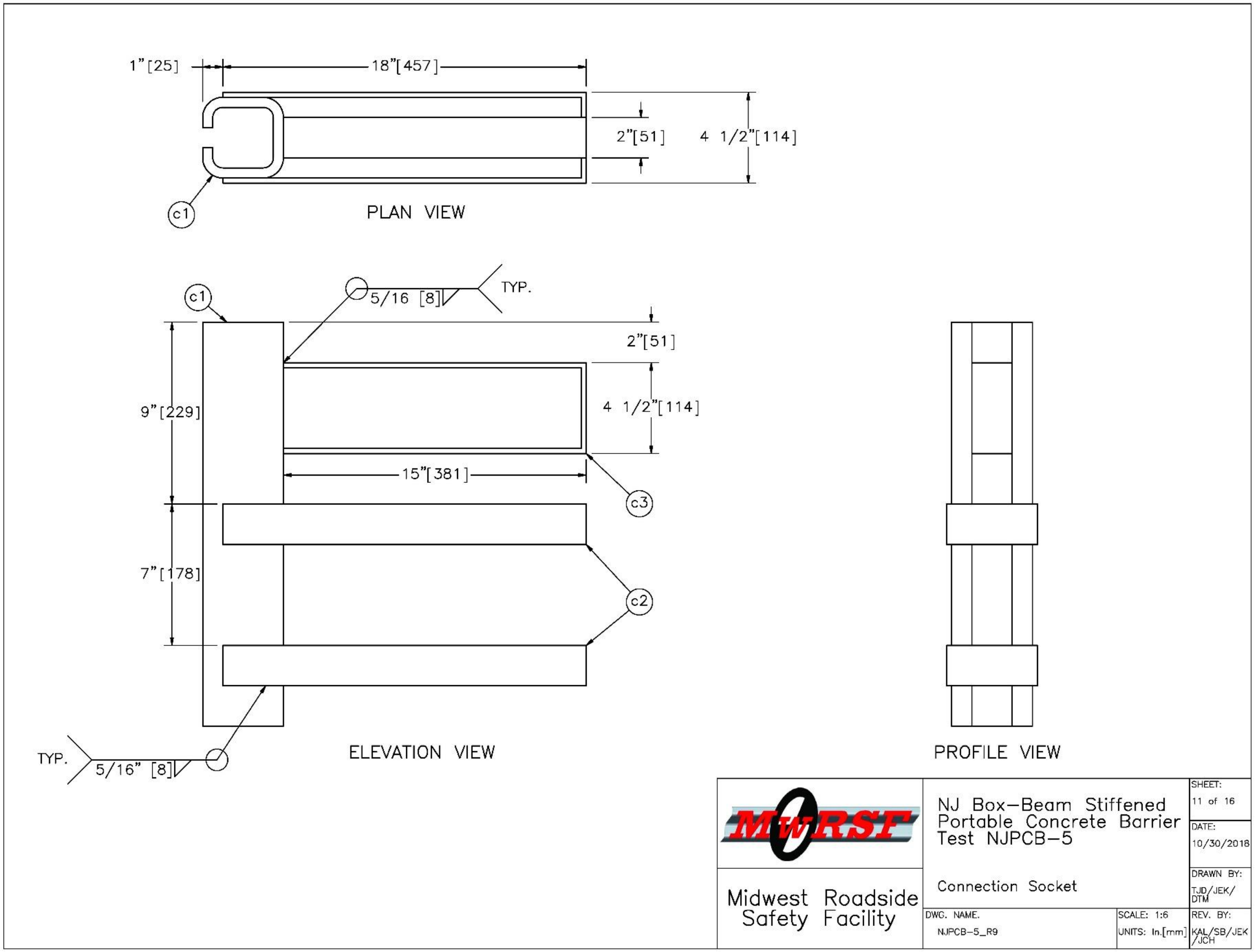


Figure 11. PCB Connection Socket Details, Test No. NJPCB-5

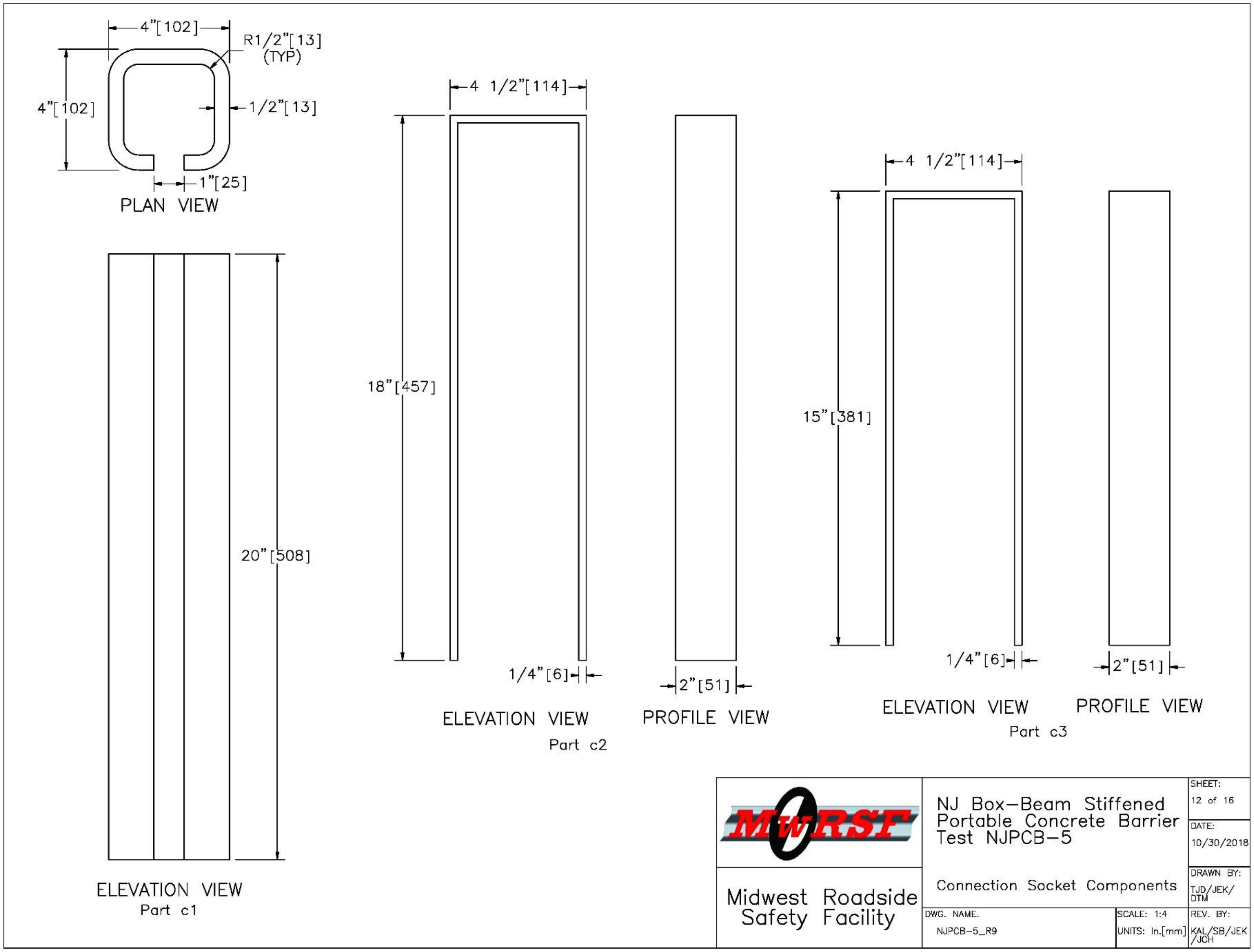


Figure 12. PCB Connection Socket Component Details, Test No. NJPCB-5

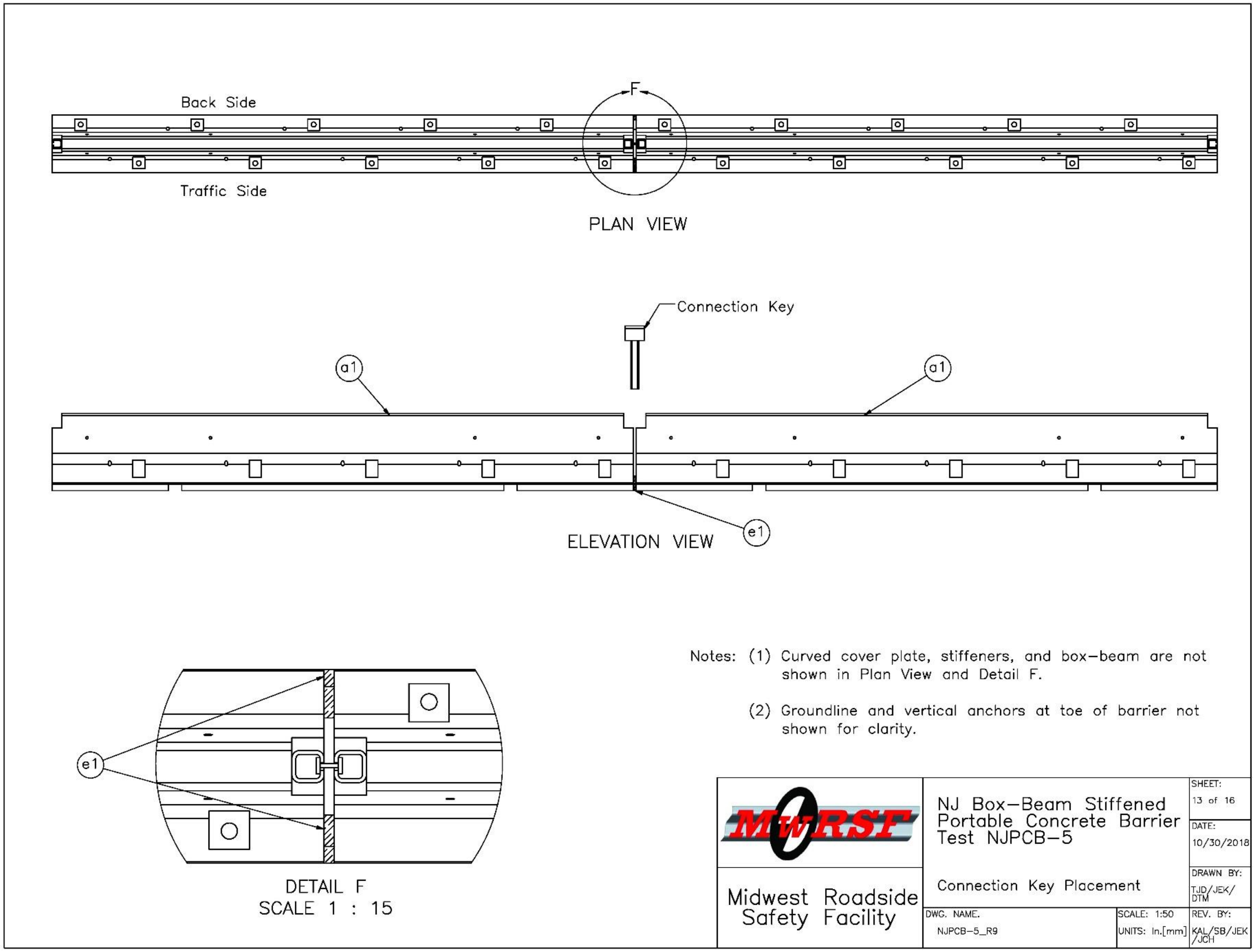
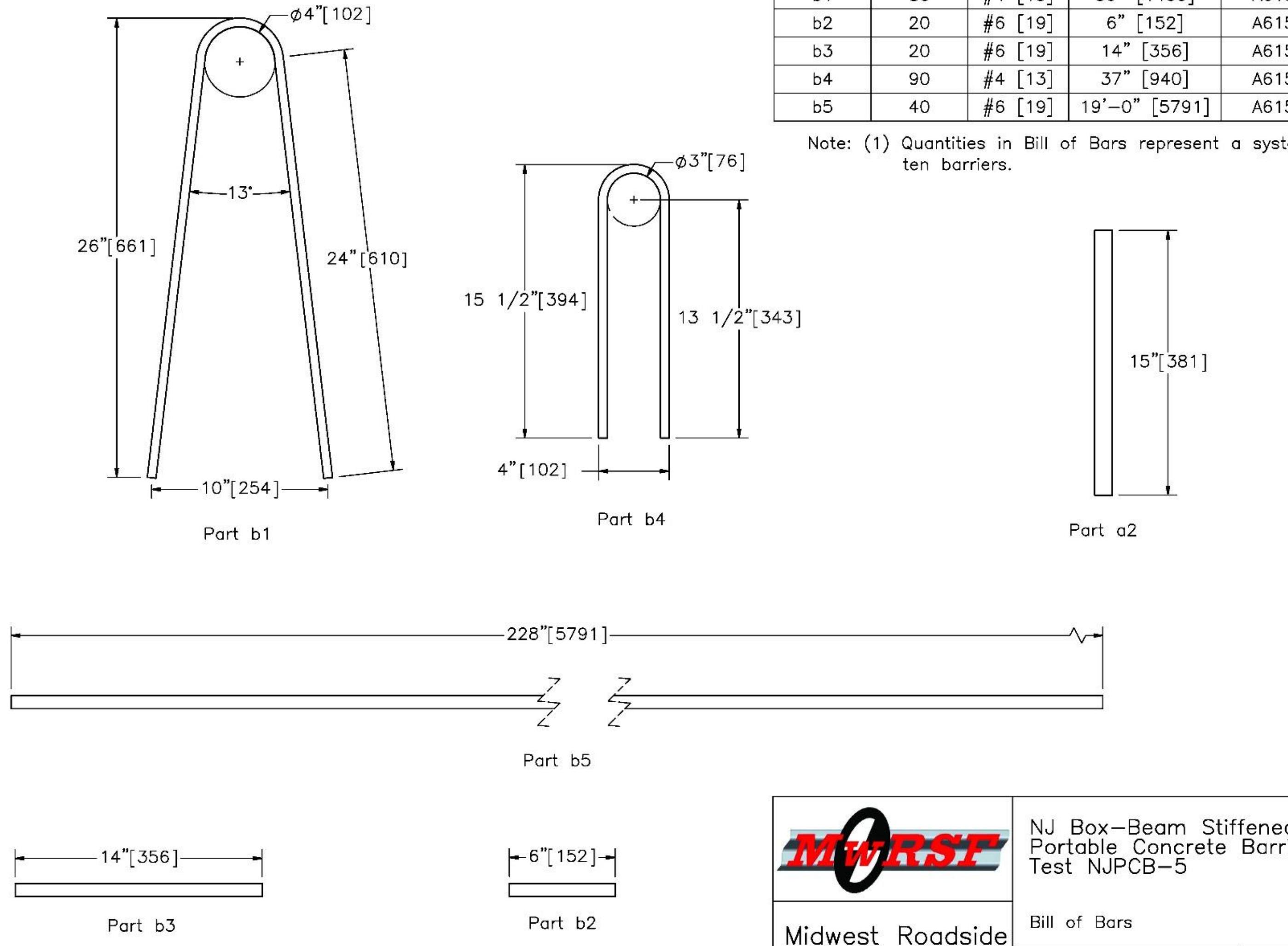


Figure 13. Connection Key Placement Details, Test No. NJPCB-5

BILL OF BARS				
ITEM NO.	QTY.	BAR SIZE	TOTAL LENGTH	MATERIAL SPEC.
a2	18	ϕ1" [25]	15" [381]	A36
b1	80	#4 [13]	59" [1499]	A615 Gr. 60
b2	20	#6 [19]	6" [152]	A615 Gr. 60
b3	20	#6 [19]	14" [356]	A615 Gr. 60
b4	90	#4 [13]	37" [940]	A615 Gr. 60
b5	40	#6 [19]	19'–0" [5791]	A615 Gr. 60

Note: (1) Quantities in Bill of Bars represent a system with ten barriers.



MwRSF

Midwest Roadside Safety Facility

NJ Box–Beam Stiffened Portable Concrete Barrier Test NJPCB–5

Bill of Bars

SHEET: 14 of 16

DATE: 10/30/2018

DRAWN BY: TJD/JEK/DTM

DWG. NAME. NJPCB–5_R9

SCALE: 1:8

UNITS: In.[mm]

REV. BY: KAL/SB/JEK/JCH

Figure 14. PCB Reinforcement Details, Test No. NJPCB-5

(1) Minimum concrete clear cover for reinforcement steel shall be 1 1/2" [38 mm].

(2) All end segments shall be pinned.

(3) After a segment has been placed and the connection key inserted, pull the unit in a direction parallel to its longitudinal axis to remove any slack in the joint.

(4) The portable concrete barrier shall be cast in steel forms.

(5) The portable concrete barrier shall be barrier segments of 20 feet [6,096 mm]. However, other lengths may be used to meet field conditions. The number and placement of the b2 and b3 reinforcement steel will vary with the length of the barrier segment as shown on the table of variable reinforcement steel. The b5 reinforcement steel shall be 10" [254 mm] shorter than the nominal length of the barrier segments.

(6) Reinforcing shown is the minimum required. Additional reinforcing necessary for handling shall be the option and responsibility of the contractor.

(7) Welding and fabrication of steel structures shall be in accordance with sections 1 thru 6 of the ANSI/AASHTO/AWS D1.5 bridge welding code and section 10 of the ANSI/AWS D1 structural welding code. Surfaces to be welded shall be free of scale, slag, rust, moisture, grease or any other material that will prevent proper welding or produce objectional fumes. Welding shall be shielded metal arc welding using properly dried 5/32" [4 mm] dia. E7018 electrodes.

(8) The length of the pins shall be such that a minimum embedment length of 5" [127 mm] is obtained when embedded into concrete pavement. When anchor pins are in place, they shall not project above the plane of the concrete surface of the barrier. Holes in bridge decks shall be 1 1/4" [32 mm] diameter maximum and made with a core drill or any other approved rotary drilling device that does not impart an impact force.

(9) Use non-shrink grout of a plastic consistency that is listed on the QPL and conforms to ASTM C 1107 with the following amendments:
1. Ensure that the grout has a working time of at least 30 minutes from the time the water is added.
2. Match the color of the hardened grout, where visible, to the color of the adjacent hardened concrete.
3. Include 1-day strength tests as part of the performance requirements of ASTM C 1107.
4. Ensure that the grout contains no more than 0.05 percent chlorides or 5.0 percent sulfates by weight.
5. Minimum 1-day compressive strength of 1,000 psi [6.9 MPa].

(10) Use connection key in every joint. Pin end segments with pins in every anchor pin recess.

(11) The box-beam is to be in accordance with the requirements of the standard specifications.

(12) The shimming consists of 8"x8"x1/2" [203x203x13 mm] square plate and fender washers as needed to snug the box-beam stiffener to the portable concrete barrier.

(13) The presence of normal holes drilled per this sheet will not affect the reusability of the concrete segments.

(14) Drill holes in the portable concrete barrier for purpose of box-beam attachment using a core drill or any other approved rotary drilling device that does not impart an impact force.

MwRSF Midwest Roadside Safety Facility	NJ Box-Beam Stiffened Portable Concrete Barrier Test NJPCB-5	SHEET: 15 of 16
		DATE: 10/30/2018
	General Notes	DRAWN BY: TJD/JEK/DTM
	DWG. NAME. NJPCB-5_R9	SCALE: None UNITS: In.[mm]	REV. BY: KAL/SB/JEK/JCH

Figure 15. General Notes, Test No. NJPCB-5

Item No.	QTY.	Description	Material Spec	Galvanization Spec
a1	10	Concrete Barrier Segment – NJDOT Type 4 Barrier (Alternate B)	Min. f'c = 3,700 psi [25.5 MPa]	–
a2	18	1" [25] Dia., 15" [381] Long Steel Anchor Pin	ASTM A36	* ASTM A123
b1	80	1/2" [13] Dia., 59" [1,499] Long Bent Rebar	ASTM A615 Gr. 60	–
b2	20	3/4" [19] Dia., 6" [152] Long Rebar	ASTM A615 Gr. 60	–
b3	20	3/4" [19] Dia., 14" [356] Long Rebar	ASTM A615 Gr. 60	–
b4	90	1/2" [13] Dia., 37" [940] Long Bent Rebar	ASTM A615 Gr. 60	–
b5	40	3/4" [19] Dia., 228" [5,791] Long Rebar	ASTM A615 Gr. 60	–
c1	20	4"x4"x1/2" [102x102x13] x 20" [508] Long Tube	ASTM A500 Gr. B or C	–
c2	40	40 1/2"x2"x1/4" [1,029x51x6] Bent Steel Plate	ASTM A36	–
c3	20	34 1/2"x2"x1/4" [876x51x6] Bent Steel Plate	ASTM A36	–
d1	18	25 1/2"x2"x1/2" [648x51x13] Steel Plate	ASTM A36	–
d2	9	25 1/2"x2 1/4"x1/2" [648x57x13] Steel Plate	ASTM A36	–
d3	18	6 3/16"x1 3/8"x1/2" [157x35x13] Steel Plate – Stiffener	ASTM A36	–
d4	9	17"x8"x1/2" [432x203x13] Bent Steel Plate – Top Plate	ASTM A36	–
e1	1	Non-Shrink Grout	Min. 1-day Compressive Strength 1,000 psi [6.9 MPa]	–
f1	9	6"x6"x3/16" [152x152x5] x 144" [3,658] Long Box Beam	ASTM A500 Gr. C	* ASTM A123
f2	36	8"x8"x1/2" [203x203x13] Steel Plate	ASTM A36	* ASTM A123
f3	36	3/4" [19] Dia., 17" [432] Long Carriage Bolt without Square Neck and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	* ASTM A153 or B695 Class 55 or F2329
f4	36	3/4" [19] Dia. Fender Washer	ASTM F844	* ASTM A123 or A153 or F2329

* Component does not need to be galvanized for testing purposes.

Midwest Roadside Safety Facility

NJ Box-Beam Stiffened Portable Concrete Barrier Test NJPCB-5

Bill of Materials

SHEET: 16 of 16
DATE: 10/30/2018
DRAWN BY: TJD/JEK/DTM
DWG. NAME. NJPCB-5_R9
SCALE: None
UNITS: In.[mm]
REV. BY: KAL/SB/JEK/JCH

Figure 16. Bill of Materials, Test No. NJPCB-5

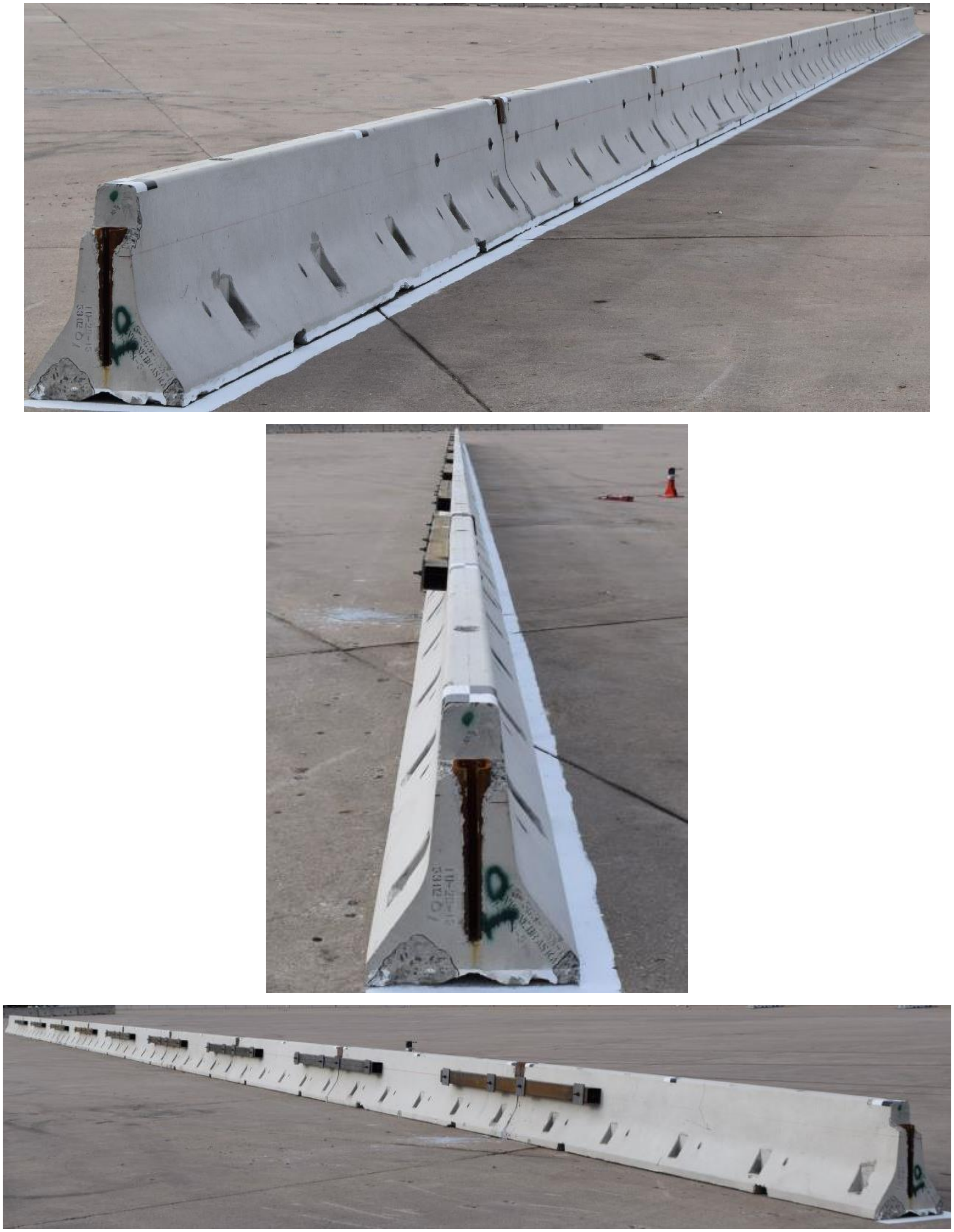


Figure 17. NJDOT PCB with Box-Beam Stiffened Configuration and Grouted Toes Test Installation, Test No. NJPCB-5

Figure 18. PCB Box-Beam Stiffeners Across Barrier Joints, Test No. NJPCB-5

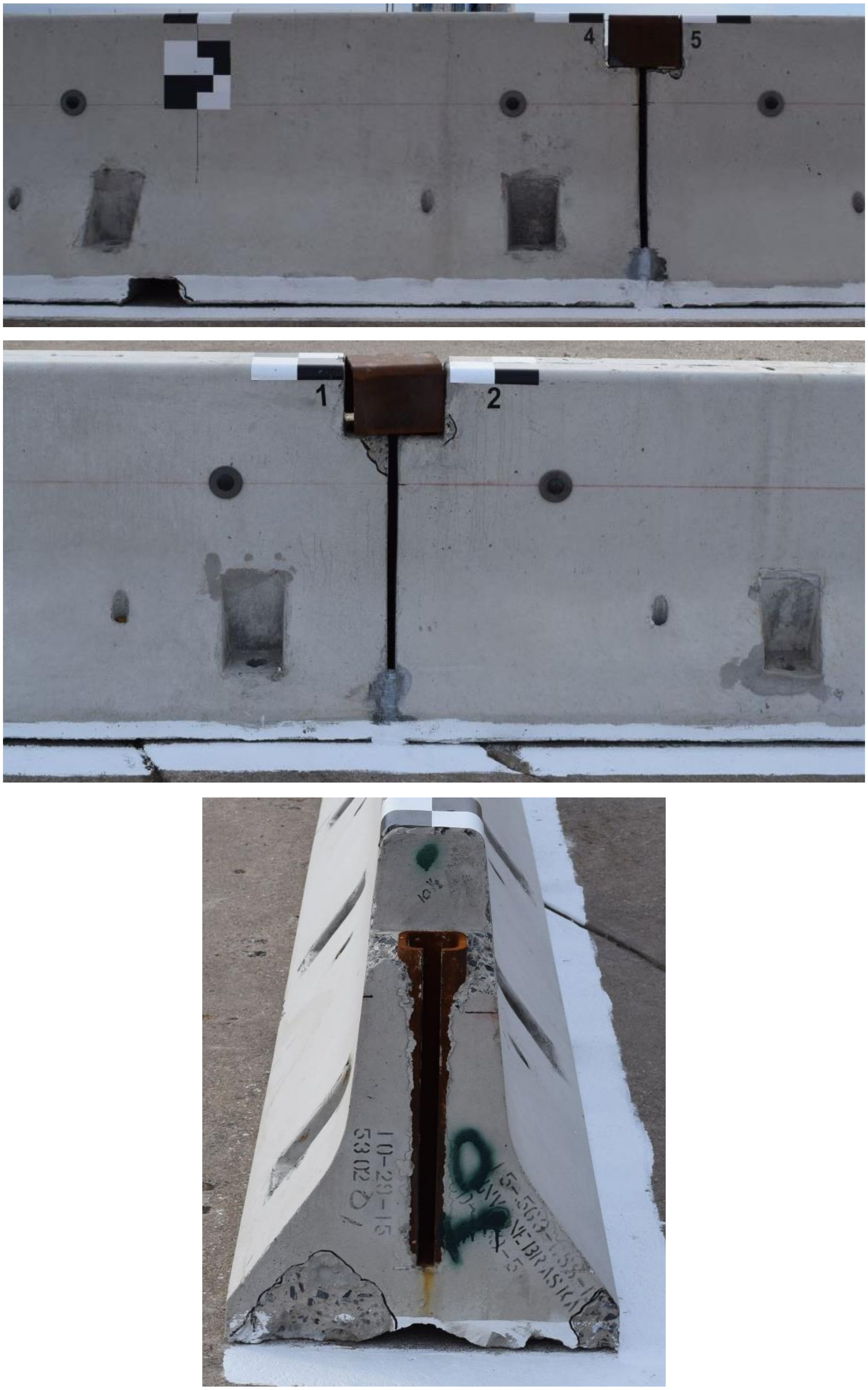


Figure 19. PCB Connection Key, Connection Socket, and Grout at Toes Between Barriers, Test No. NJPCB-5

4 TEST CONDITIONS

4.1 Test Facility

The Outdoor Test Site is located at the Lincoln Air Park on the northwest side of the Lincoln Municipal Airport and is approximately 5 miles (8.0 km) northwest of the University of Nebraska-Lincoln.

4.2 Vehicle Tow and Guidance System

A reverse-cable, tow system with a 1:2 mechanical advantage was used to propel the test vehicle. The distance traveled and the speed of the tow vehicle were one-half that of the test vehicle. The test vehicle was released from the tow cable before impact with the barrier system. A digital speedometer on the tow vehicle increased the accuracy of the test vehicle impact speed.

A vehicle guidance system developed by Hinch [11] was used to steer the test vehicle. A guide flag, attached to the right-front wheel and the guide cable, was sheared off before impact with the barrier system. The ⅜-in. (9.5-mm) diameter guide cable was tensioned to approximately 3,500 lb (15.6 kN) and supported both laterally and vertically every 100 ft (30.5 m) by hinged stanchions. The hinged stanchions stood upright while holding up the guide cable, but as the vehicle was towed down the line, the guide flag struck and knocked each stanchion to the ground.

4.3 Test Vehicle

For test no. NJPCB-5, a 2009 Dodge Ram 1500 quad cab pickup truck was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 5,084 lb (2,306 kg), 5,001 lb (2,268 kg), and 5,162 lb (2,341 kg), respectively. The test vehicle is shown in Figures 20 and 21, and vehicle dimensions are shown in Figure 22. Note that pre-test photographs of the vehicle's undercarriage are not available.

The longitudinal component of the center of gravity (c.g.) was determined using the measured axle weights. The Suspension Method [12] was used to determine the vertical component of the c.g. for the pickup truck. This method is based on the principle that the c.g. of any freely suspended body is in the vertical plane through the point of suspension. The vehicle was suspended successively in three positions, and the respective planes containing the c.g. were established. The intersection of these planes pinpointed the final c.g. location for the test inertial condition. The location of the final c.g. is shown in Figures 22 and 23. Data used to calculate the location of the c.g. and ballast information are shown in Appendix D.

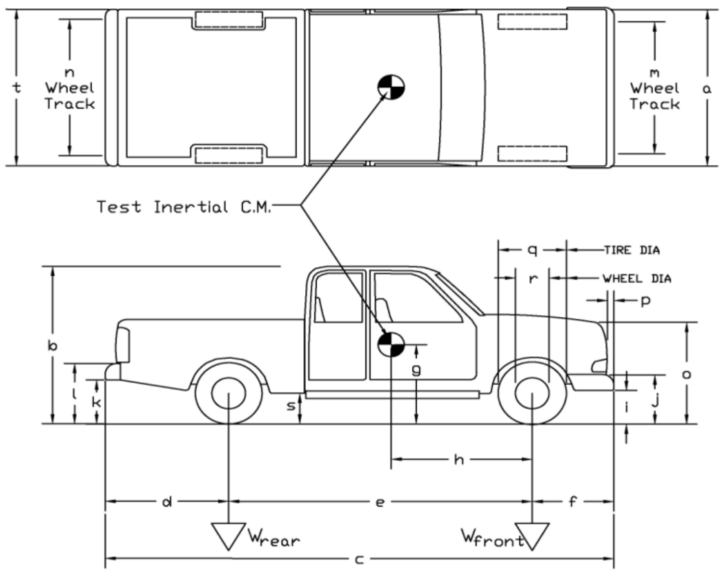
Square, black- and white-checkered targets were placed on the vehicle for reference to be viewed from the high-speed digital video cameras and aid in the video analysis, as shown in Figure 23. Round, checkered targets were placed on the c.g. on the left-side door, the right-side door, and the roof of the vehicle.

The front wheels of the test vehicle were aligned to vehicle standards except the toe-in value was adjusted to zero such that the vehicle would track properly along the guide cable. A 5B flash bulb was mounted under the vehicle's left-side windshield wiper and was fired by a pressure tape switch mounted at the impact corner of the bumper. The flash bulb was fired upon initial impact with the test article to create a visual indicator of the precise time of impact on the high-speed digital videos. A remote-controlled brake system was installed in the test vehicle so the vehicle could be brought safely to a stop after the test.

Figure 20. Test Vehicle, Test No. NJPCB-5

Figure 21. Test Vehicle's Interior Floorboards, Test No. NJPCB-5

Date:	1/31/2017	Test Name:	NJPCB-5	VIN No:	1D3HB18P19S779289
Year:	2009	Make:	Dodge	Model:	Ram
Tire Size:	275/60R20	Tire Inflation Pressure:	35 Psi	Odometer:	156834



Vehicle Geometry - in. (mm)
Target Ranges listed below

a:	76 7/8	(1953)	b:	74 1/2	(1892)
	78±2 (1950±50)				
c:	229 1/4	(5823)	d:	49 1/4	(1251)
	237±13 (6020±325)				
e:	139 7/8	(3553)	f:	39 7/8	(1013)
	148±12 (3760±300)			39±3 (1000±75)	
g:	28 7/8	(732)	h:	61 5/8	(1564)
	min: 28 (710)			63±4 (1575±100)	
i:	8 1/8	(206)	j:	27	(686)
k:	21	(533)	l:	30 1/2	(775)
m:	68 1/4	(1734)	n:	68 3/8	(1737)
	67±1.5 (1700±38)			67±1.5 (1700±38)	
o:	45 3/4	(1162)	p:	4	(102)
	43±4 (1100±75)				
q:	33 1/4	(845)	r:	21 5/8	(549)
s:	14	(356)	t:	78 5/8	(1997)

Wheel Center Height (Front):	15 3/8	(391)
Wheel Center Height (Rear):	15 5/8	(397)
Wheel Well Clearance (Front):	35 1/8	(892)
Wheel Well Clearance (Rear):	38 1/8	(968)
Bottom Frame Height (Front):	13 3/4	(349)
Bottom Frame Height (Rear):	26 1/8	(664)
Engine Type:	Gasoline	
Engine Size:	4.7L V8	
Transmission Type:	Automatic	
Drive Type:	RWD	
Cab Style:	Quad Cab	
Bed Length:	76"	

Mass Distribution lb (kg)

Gross Static	LF	1488	(675)	RF	1409	(639)
	LR	1136	(515)	RR	1129	(512)

Weights lb (kg)	Curb		Test Inertial		Gross Static	
W-front	2859	(1297)	2799	(1270)	2897	(1314)
W-rear	2225	(1009)	2202	(999)	2265	(1027)
W-total	5084	(2306)	5001	(2268)	5162	(2341)
			5000±110 (2270±50)		5165±110 (2343±50)	

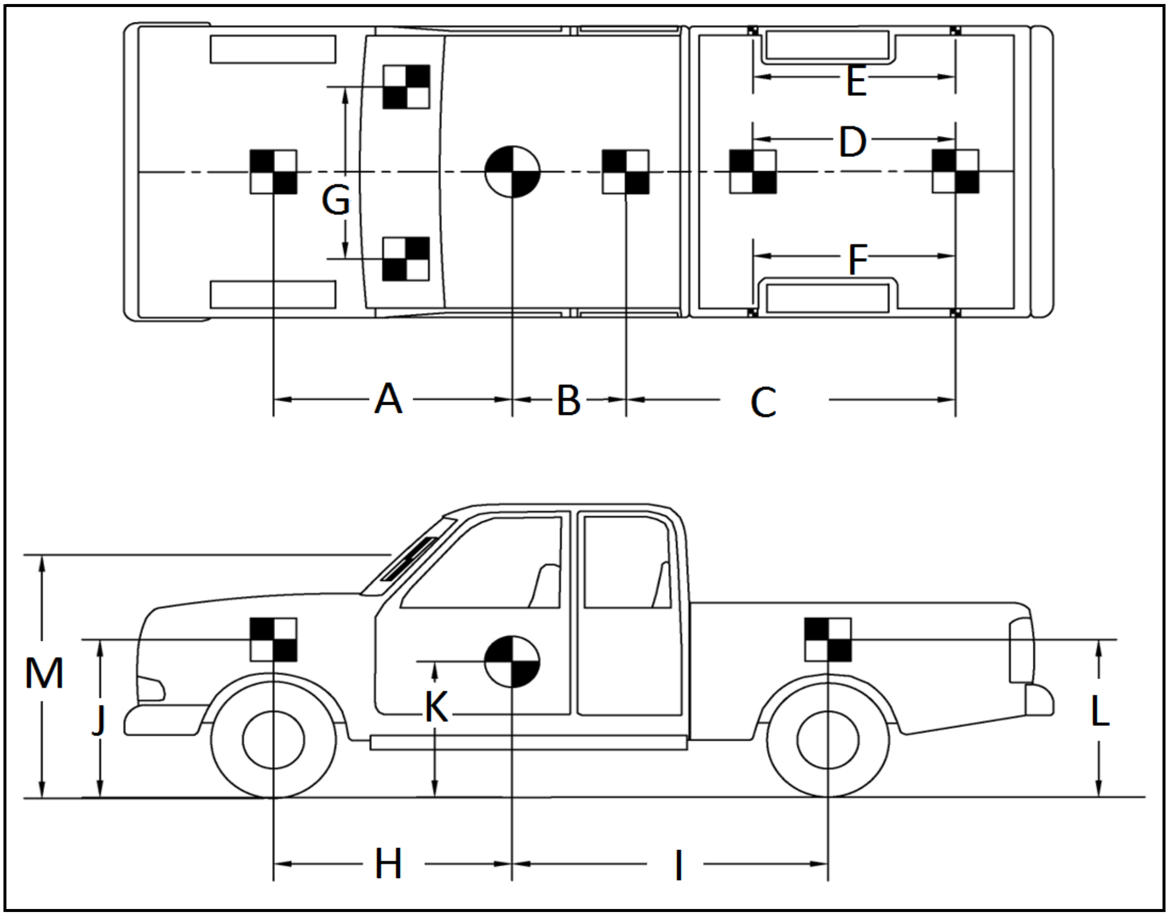
GVWR Ratings lb	
Front	3700
Rear	3900
Total	6700

Dummy Data	
Type:	Hybrid II
Mass:	161 lb
Seat Position:	Driver

Note any damage prior to test: Some dents on oth sides of the bed

Figure 22. Vehicle Dimensions, Test No. NJPCB-5

Date:	1/31/2017	**Test Name:**	NJPCB-5	**VIN:**	1D3HB18P19S779289
Year:	2009	**Make:**	Dodge	**Model:**	Ram



TARGET GEOMETRY-- in. (mm)

A:	77 1/4	(1962)	**E:**	63 1/8	(1603)	**J:**	39 3/8	(999)
B:	30 1/4	(768)	**F:**	63 1/8	(1603)	**K:**	28 7/8	(732)
C:	71 3/8	(1813)	**G:**	34 1/4	(870)	**L:**	42 1/4	(1073)
D:	48	(1219)	**H:**	61 5/8	(1564)	**M:**	64 7/8	(1648)
			I:	78 7/8	(2003)			

Figure 23. Target Geometry, Test No. NJPCB-5

4.4 Simulated Occupant

For test no. NJPCB-5, A Hybrid II 50th-Percentile, Adult Male Dummy, equipped with clothing and footwear, was placed in the left-front seat of the test vehicle with the seat belt fastened. The dummy, which had a final weight of 161 lb (73 kg), was represented by model no. 572, serial no. 451, and was manufactured by Android Systems of Carson, California. As recommended by MASH 2016, the dummy was not included in calculating the c.g. location.

4.5 Data Acquisition Systems

4.5.1 Accelerometers

Two environmental shock and vibration sensor/recorder systems were used to measure the accelerations in the longitudinal, lateral, and vertical directions. All of the accelerometers were mounted near the c.g. of the test vehicle. The electronic accelerometer data obtained in dynamic testing was filtered using the SAE Class 60 and the SAE Class 180 Butterworth filter conforming to the SAE J211/1 specifications [13].

The first accelerometer system, the SLICE-2 unit, was a modular data acquisition system manufactured by Diversified Technical Systems, Inc. (DTS) of Seal Beach, California. The SLICE-2 unit was designated as the primary system. The acceleration sensors were mounted inside the body of custom-built, SLICE 6DX event data recorder and recorded data at 10,000 Hz to the onboard microprocessor. The SLICE 6DX was configured with 7 GB of non-volatile flash memory, a range of ±500 g's, a sample rate of 10,000 Hz, and a 1,650 Hz (CFC 1000) anti-aliasing filter. The "SLICEWare" computer software programs and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

The second accelerometer system was a two-arm piezoresistive accelerometer system manufactured by Endevco of San Juan Capistrano, California. Three accelerometers were used to measure each of the longitudinal, lateral, and vertical accelerations independently at a sample rate of 10,000 Hz. The accelerometers were configured and controlled using a system developed and manufactured by DTS of Seal Beach, California. More specifically, data was collected using a DTS Sensor Input Module (SIM), Model TDAS3-SIM-16M. The SIM was configured with 16 MB SRAM and 8 sensor input channels with 250 kB SRAM/channel. The SIM was mounted on a TDAS3-R4 module rack. The module rack was configured with isolated power/event/communications, 10BaseT Ethernet and RS232 communication, and an internal backup battery. Both the SIM and module rack were crashworthy. The "DTS TDAS Control" computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

4.5.2 Rate Transducers

The first angular rate sensor system, which was mounted inside the body of the SLICE-2 event data recorder, measured the rates of rotation of the test vehicle. The SLICE MICRO Triax ARS had a range of 1,500 degrees/sec in each of the three directions (roll, pitch, and yaw) and recorded data at 10,000 Hz to the onboard microprocessors. The raw data measurements were then downloaded, converted to the proper Euler angles for analysis, and plotted. The "SLICEWare" computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the angular rate sensor data.

The second angular rate sensor, the ARS-1500, with a range of 1,500 degrees/sec in each of the three directions (roll, pitch, and yaw) was used to measure the rates of rotation of the test vehicle. The angular rate sensor was mounted on an aluminum block inside the test vehicle near the c.g. and recorded data at 10,000 Hz to the DTS SIM. The raw data measurements were then downloaded, converted to the proper Euler angles for analysis, and plotted. The “DTS TDAS Control” computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the angular rate sensor data.

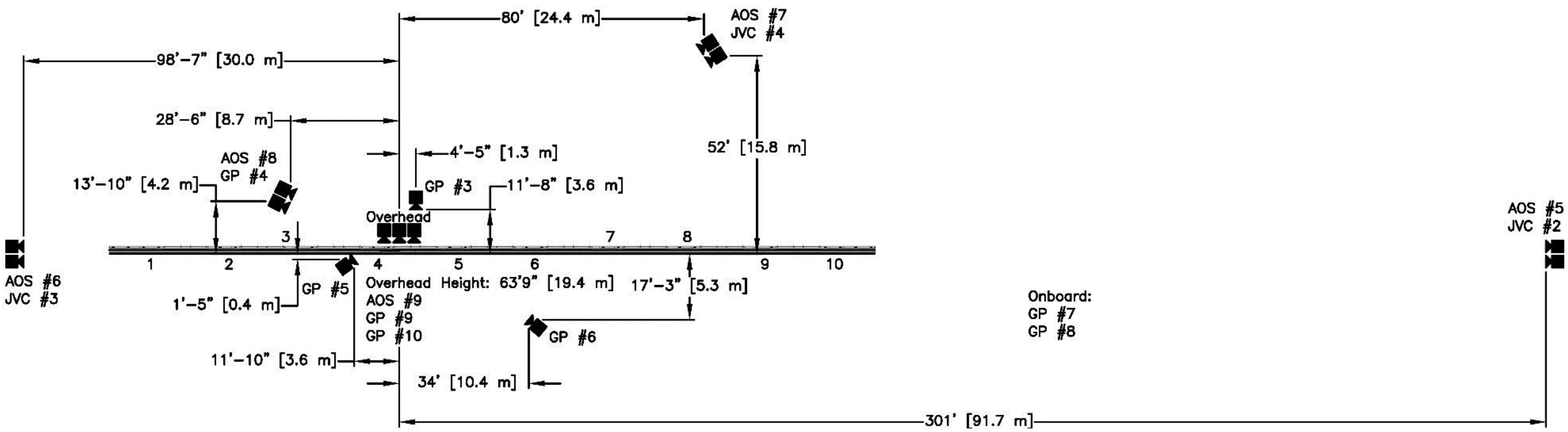
4.5.3 Retroreflective Optic Speed Trap

The retroreflective optic speed trap was used to determine the speed of the test vehicle before impact. Five retroreflective targets, spaced at approximately 18-in. (457-mm) intervals, were applied to the side of the vehicle. When the emitted beam of light was reflected by the targets and returned to the Emitter/Receiver, a signal was sent to the data acquisition computer, recording at 10,000 Hz, as well as the external LED box activating the LED flashes. The speed was then calculated using the spacing between the retroreflective targets and the time between the signals. LED lights and high-speed digital video analysis are only used as a backup in the event that vehicle speeds cannot be determined from the electronic data.

4.5.4 Digital Photography

Five AOS high-speed digital video cameras, eight GoPro digital video cameras, and three JVC digital video cameras were utilized to film test no. NJPCB-5. Camera details, camera operating speeds, lens information, and a schematic of the camera locations relative to the system are shown in Figure 24.

The high-speed digital videos were analyzed using TEMA Motion and RedLake MotionScope software programs. Actual camera speed and camera divergence factors were considered in the analysis of the high-speed digital videos. A Nikon digital still camera was also used to document pre- and post-test conditions for the test.



No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
AOS-5	AOS X-PRI Gigabit	500	Vivitar 135mm	-
AOS-6	AOS X-PRI Gigabit	500	Fujinon 35mm	-
AOS-7	AOS X-PRI Gigabit	500	Fujinon 50mm	-
AOS-8	AOS S-VIT 1531	500	Kowa 16mm	-
AOS-9	AOS TRI-VIT	1000	Kowa 12mm	-
GP-3	GoPro Hero 3+	120		
GP-4	GoPro Hero 3+	120		
GP-5	GoPro Hero 3+	120		
GP-6	GoPro Hero 3+	120		
GP-7	GoPro Hero 4	120		
GP-8	GoPro Hero 4	120		
GP-9	GoPro Hero 4	240		
GP-10	GoPro Hero 4	120		
JVC-2	JVC – GZ-MG27u (Everio)	29.97		
JVC-3	JVC – GZ-MG27u (Everio)	29.97		
JVC-4	JVC – GZ-MG27u (Everio)	29.97		

Figure 24. Camera Locations, Speeds, and Lens Settings, Test No. NJPCB-5

5 FULL-SCALE CRASH TEST NO. NJPCB-5

5.1 Weather Conditions

Test no. NJPCB-5 was conducted on January 31, 2017 at approximately 2:40 p.m. The weather conditions as per the National Oceanic and Atmospheric Administration (station 14939/LNK) were reported and are shown in Table 5.

Table 5. Weather Conditions, Test No. NJPCB-5

Temperature	27° F
Humidity	51%
Wind Speed	7 mph
Wind Direction	350° from True North
Sky Conditions	Overcast
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.00 in.
Previous 7-Day Precipitation	0.10 in.

5.2 Test Description

The 5,001-lb (2,268-kg) pickup truck impacted the NJDOT PCB, Type 4 (Alternative B) with a box-beam stiffened configuration and grouted toes, corresponding to connection type B in the 2015 NJDOT *Roadway Design Manual*, at a speed of 62.7 mph (100.8 km/h) and at an angle of 24.9 degrees. A summary of the test results and sequential photographs are shown in Figure 26. Additional sequential photographs are shown in Figures 27 and 28. Documentary photographs of the crash test are shown in Figures 29 through 32.

Initial vehicle impact was to occur 4 ft – 3$^{3}/_{16}$ in. (1.3 m) upstream from the centerline of the joint between barrier nos. 4 and 5, as shown in Figure 33, which was selected using Table 2.7 of MASH 2016. The actual point of impact was 1¾ in. (45 mm) downstream of the target location. A sequential description of the impact events is contained in Table 6. The vehicle came to rest 234 ft – 11 in. (71.6 m) downstream from the impact point and 48 ft – 10 in. (14.9 m) laterally away from the traffic side of the system after brakes were applied. The vehicle trajectory and final position are shown in Figures 26 and 34.

Table 6. Sequential Description of Impact Events, Test No. NJPCB-5

TIME (sec)	EVENT
0.000	Vehicle’s left-front tire impacted barrier no. 4 at 4 ft – 1$^{7}/_{16}$ in. (1.3 m) upstream from centerline of joint between barrier nos. 4 and 5.
0.006	Vehicle’s left-front bumper contacted barrier no. 4 and deformed.
0.010	Vehicle’s left headlight contacted top of barrier no. 4 and deformed.
0.014	Vehicle’s left fender contacted barrier no. 4 and deformed.

0.022	Vehicle’s hood and grille contacted barrier no. 4 and deformed.
0.030	Downstream end of barrier no. 4 deflected backward.
0.034	Vehicle’s right-front fender deformed.
0.037	Vehicle yawed away from barrier. Vehicle’s left headlight contacted barrier no. 5.
0.044	Vehicle pitched upward.
0.046	Upstream end of barrier no. 5 deflected backward. Upstream end of barrier no. 4 spalled.
0.056	Vehicle’s left-rear door deformed.
0.058	Downstream end of barrier no. 5 spalled.
0.064	Vehicle’s left fender contacted barrier no. 5.
0.076	Vehicle rolled toward system.
0.082	Vehicle’s left-front door contacted barrier no. 5.
0.092	Vehicle’s right-front tire became airborne.
0.118	Barrier no. 5 fractured between midspan and upstream end.
0.122	Downstream end of barrier no. 3 deflected backward. Barrier nos. 4 and 5 continued to deflect backward. Upstream end of barrier no. 6 deflected backward.
0.197	Vehicle was parallel to system at a speed of 52.4 mph (84.3 km/h).
0.200	Vehicle’s left-rear door contacted barrier no. 5.
0.205	Upstream end of barrier no. 7 spalled. Vehicle’s left-rear quarter panel contacted barrier no. 5.
0.210	Vehicle’s left-rear tire contacted barrier no. 5.
0.216	Vehicle’s left taillight contacted barrier no. 4 and deformed.
0.226	Vehicle pitched downward.
0.234	Traffic-side downstream end of barrier no. 4 spalled.
0.238	Vehicle’s right-rear tire became airborne.
0.262	Barrier no. 3 deflected backward.
0.268	Traffic-side upstream end of barrier no. 5 spalled.
0.304	Barrier no. 6 deflected backward.
0.324	Upstream end of barrier no. 7 deflected backward.
0.400	Vehicle’s left-front tire regained contact with ground.
0.506	Vehicle’s right-front tire regained contact with ground.
0.516	Vehicle rolled away from system.
0.522	Vehicle’s front bumper contacted ground.
0.558	Vehicle exited system at a speed of 48.9 mph (78.7 km/h) and at an angle of 4.9 degrees.
0.642	Vehicle pitched upward.
0.676	Vehicle rolled toward system.
0.848	Vehicle rolled away from system.
1.008	Vehicle’s right-rear tire regained contact with ground.
1.152	Vehicle pitched downward.
1.168	Vehicle rolled toward system.
1.518	Vehicle pitched upward.
1.658	Vehicle’s left-rear tire disengaged.

5.3 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 35 through 43. Barrier damage consisted of contact marks on the front face of the concrete segments, spalling of the concrete, and concrete cracking. The length of vehicle contact along the barrier was approximately 24 ft – 7½ in. (7.5 m), which spanned from 5 ft – 7 in. (1.7 m) upstream from the center of the joint between barrier nos. 4 and 5 to 19 ft – ½ in. (5.8 m) downstream from the center of the joint between barrier nos. 4 and 5.

Tire marks were visible on the front face of barrier nos. 4 and 5. Scrape marks were found on the front and top faces of barrier nos. 4 and 5. Grout between barrier nos. 4 and 5 crumbled. Cracks extended from the front, across the top, and onto the back face of barrier no. 2 at 60 in. (1,524 mm), 84 in. (2,134 mm), and 108 in. (2,743 mm) upstream from the downstream end of the barrier. A crack was found the on front, top, and back faces of barrier no. 3 and was located 58 in. (1,473 mm) downstream from the center of the barrier. A crack was found on the front, top, and back faces of barrier no. 4 and was located 6 in. (152 mm) upstream from the downstream edge of the barrier. A crack was found on the front, top, and back faces of barrier no. 5 and was located 83 in. (2,108 mm) downstream from the upstream edge of the barrier. Minor cracks were also found on the front and back faces of barrier nos. 3, 6, 7, and 8.

Minimal concrete spalling occurred on the back face of barrier no. 2 at the upstream and downstream ends. A 7-in. × 5-in. × ½-in. (178-mm × 127-mm × 13-mm) piece of concrete disengaged from barrier no. 3 at the lower-downstream corner on the back face. A 21-in. × 7-in. × 4-in. (533-mm × 178-mm × 102-mm) piece of concrete was removed from the lower-downstream end of the front face of barrier no. 4. A 33-in. × 9-in. × 3½-in. (838-mm × 229-mm × 89-mm) piece of concrete disengaged from the back face of barrier no. 4 at the lower-upstream corner. Concrete spalling, measuring 28 in. × 8½ in. × 6 in. (711 mm × 216 mm × 152 mm), occurred on the front face of barrier no. 5 at the upstream end. The back face of barrier no. 5 experienced 52-in. × 10-in. × 3½-in. (1,321-mm × 254-mm × 89-mm) concrete spalling at the lower-downstream corner. Concrete spalling, measuring 3 in. × 6 in. × 1½ in. (76 mm × 152 mm × 38 mm), occurred on the back face of barrier no. 6 at the downstream end. A 20-in. × 8½-in. × 2½-in. (508-mm × 216-mm × 64-mm) piece of concrete disengaged from the back face of barrier no. 7 at the lower-downstream edge. Concrete spalling, measuring 11½ in. × 6 in. × 2 in. (292 mm × 152 mm × 51 mm), occurred on the back face of barrier no. 7 at the downstream end.

The maximum permanent set deflection of the barrier system was 32½ in. (826 mm) at the upstream end of barrier no. 5, as measured in the field. The maximum lateral dynamic barrier deflection, including tipping of the barrier along the top surface, was 33.0 in. (838 mm) at the upstream end of barrier no. 5, as determined from high-speed digital video analysis. The working width of the system was found to be 57.0 in. (1,448 mm), also determined from high-speed digital video analysis. A schematic of the permanent set deflection, dynamic deflection, and working width is shown in Figure 25. In addition, NJDOT identifies the clear space behind the barrier, which is defined as the maximum deflection of the back of the barrier from its original position. For this test, the clear space behind the barrier was 33.0 in. (838 mm).

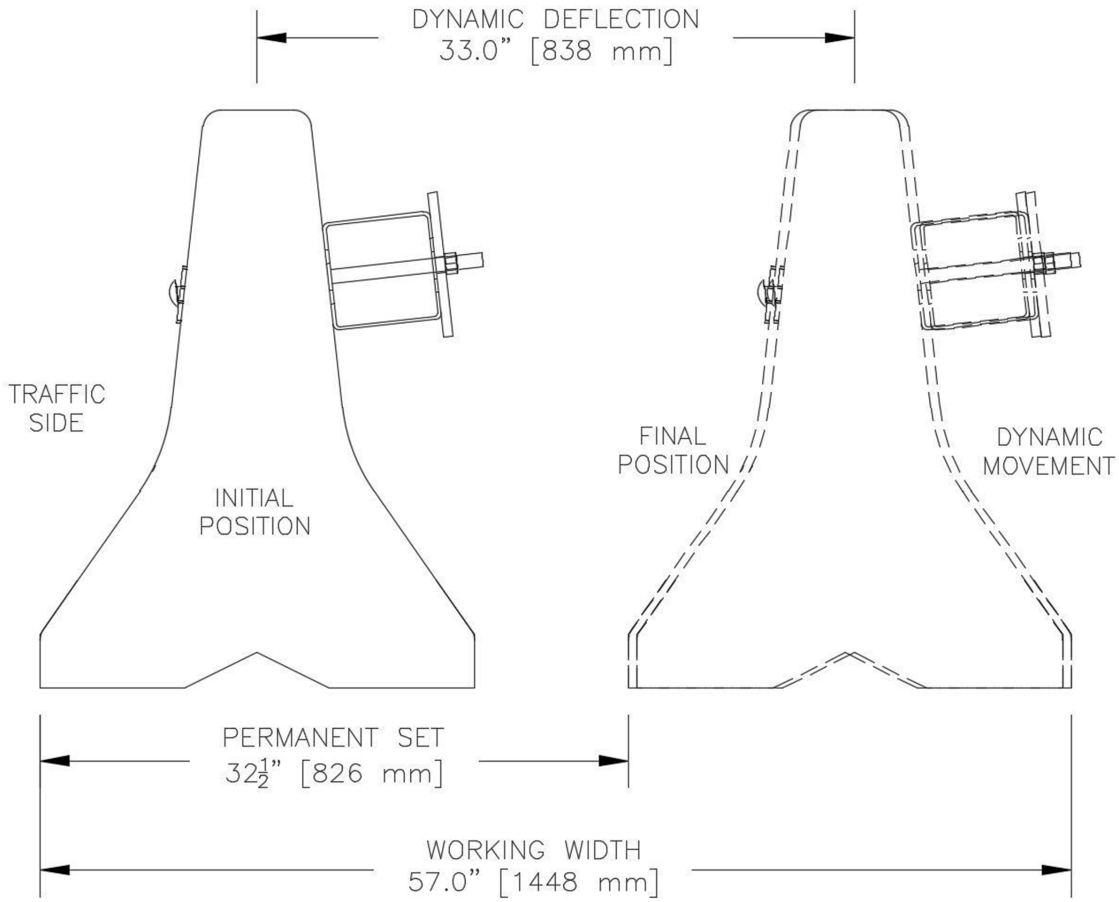


Figure 25. Permanent Set Deflection, Dynamic Deflection, and Working Width, Test No. NJPCB-5

5.4 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 44 through 48. The maximum occupant compartment deformations are listed in Table 7 along with the deformation limits established in MASH 2016 for various areas of the occupant compartment. Note that none of the established MASH 2016 deformation limits were violated. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix E.

The majority of damage was concentrated on the left-front corner and left side of the vehicle where the impact had occurred. The left side of the bumper was crushed inward and back. The left-front fender was deformed upward near the door panel and was dented and torn behind the left-front wheel. The left-side and right-side headlights disengaged. The left-front tire partially disengaged with the front portion of the brake rotor and the spindle shaft still attached to the wheel. The left corner of the front bumper was bent inward approximately 30 in. (762 mm) from the left side. The left-front corner of the frame rail buckled inward. The left side of the lower plastic fascia was partially disengaged. A 1-in (25-mm) gap occurred between the fender and the front bumper. The left-side front bottom corner of the fender buckled 6 in. (152 mm) inward. The left-front door was ajar with a gap of 1 in. (25 mm) at the top. Denting and scraping were observed on the entire left side. A 16-in. × 9-in. (406-mm × 229-mm) dent was found at the rear of the left-front door. Dents and scraping were found on the left side of the quarter panel. The left-rear tire disengaged.

The joint of the left-front sway bar was scuffed. The left-front lower control arm deflected ½ in. (13 mm) rearward. The left-front control arm deformed. A 33-in. (838-mm) diameter spider web crack was found in the lower-right corner of the windshield. The left-front and right-front airbags and left-side and right-side curtain airbags deployed. The roof and remaining window glass remained undamaged.

Table 7. Maximum Occupant Compartment Deformations by Location

LOCATION	MAXIMUM DEFORMATION in. (mm)	MASH 2016 ALLOWABLE DEFORMATION in. (mm)
Wheel Well & Toe Pan	1¾ (44)	≤ 9 (229)
Floor Pan & Transmission Tunnel	⅜ (10)	≤ 12 (305)
A-Pillar	½ (13)	≤ 5 (127)
A-Pillar (Lateral)	¼ (6)	≤ 3 (76)
B-Pillar	⅜ (10)	≤ 5 (127)
B-Pillar (Lateral)	⅜ (10)	≤ 3 (76)
Side Front Panel (in Front of A-Pillar)	⅜ (10)	≤ 12 (305)
Side Door (Above Seat)	−1 (−25)	≤ 9 (229)
Side Door (Below Seat)	¼ (6)	≤ 12 (305)
Roof	⅛ (3)	≤ 4 (102)
Windshield	0 (0)	≤ 3 (76)
Side Window	Intact	No shattering resulting from contact with structural member of test article
Dash	½ (13)	N/A

Note: Negative values denote outward deformation
N/A – Not applicable

5.5 Occupant Risk

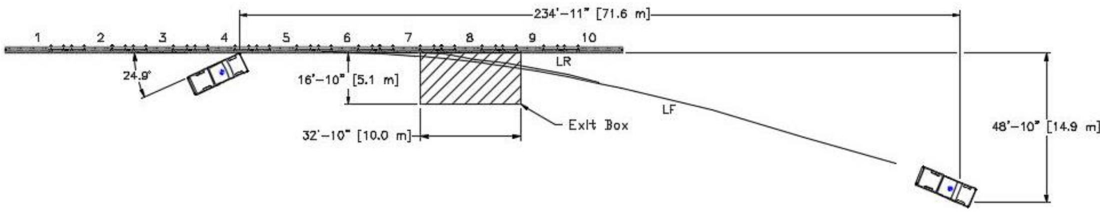
The calculated occupant impact velocities (OIVs) and maximum 0.010-sec average occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions are shown in Table 8. Note that the OIVs and ORAs were within suggested limits, as provided in MASH 2016. The calculated THIV, PHD, and ASI values are also shown in Table 8. The results of the occupant risk analysis, as determined from the accelerometer data, are summarized in Figure 26. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix F.

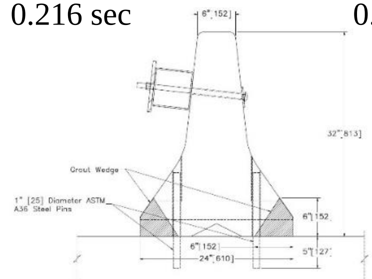
Table 8. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. NJPCB-5

Evaluation Criteria		Transducer		MASH 2016 Limits
		SLICE-2 (primary)	DTS	
OIV ft/s (m/s)	Longitudinal	-13.61 (-4.15)	-13.17 (-4.02)	±40 (12.2)
	Lateral	21.62 (6.59)	18.33 (5.59)	±40 (12.2)
ORA g's	Longitudinal	-7.65	-7.13	±20.49
	Lateral	9.62	11.15	±20.49
MAX. ANGULAR DISPL. deg.	Roll	-7.9	-8.2	±75
	Pitch	-12.5	-12.2	±75
	Yaw	42.4	45.0	not required
THIV ft/s (m/s)		26.44 (8.06)	21.75 (6.63)	not required
PHD g's		9.72	11.21	not required
ASI		1.41	1.25	not required

5.6 Discussion

The analysis of the test results for test no. NJPCB-5 showed that the system adequately contained and redirected the 2270P vehicle with controlled lateral displacements of the barrier. Detached elements, fragments, or other debris from the test article did not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or work-zone personnel. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate nor ride over the barrier and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix F, were deemed acceptable, because they did not adversely influence occupant risk nor cause rollover. After impact, the vehicle exited the barrier at an angle of 4.9 degrees, and its trajectory did not violate the bounds of the exit box. Therefore, test no. NJPCB-5 was determined to be acceptable according to the MASH 2016 safety performance criteria for test designation no. 3-11.





- Test Agency .... MwRSF
- Test Number NJPCB-5
- Date 1/31/2017
- MASH 2016 Test Designation No. 3-11
- Test Article .... Box-Beam Stiffened NJDOT PCB with Grout, Connection Type B [2]
- Total Length .... 200 ft (61.0 m)
- Key Component – NJDOT PCB
    - Length .... 20 ft (6.1 m)
    - Width .... 24 in. (610 mm)
    - Height .... 32 in. (813 mm)
- Key Component – Anchor Pins
    - Pin Size & Length .... 1-in. (25-mm) diameter × 15-in. (381-mm) long unthreaded rod
    - Pin Material .... ASTM A36 steel
    - Embedment Depth .... 5 in. (127 mm)
    - Pinned Barrier Nos. .... 1 and 10
- Key Component – Box-Beam Stiffener
    - Box Beam Size .... 6 in. × 6 in. × $^{3}/_{16}$ in. (152 mm × 152 mm × 5 mm)
    - Box Beam Length .... 144 in. (3,658 mm)
    - Box Beam Material .... ASTM A500 Grade C
    - Connector Bolt and Nut Size .... ¾-in. (19-mm) diameter × 17-in. (432-mm) long bolt
- Key Component – Grout
    - Specification .... Min. 1-day compressive strength 1,000 psi (6.9 MPa)
    - Location .... Toes at joints between barrier nos. 1-10 on traffic and back sides
- Type of Support Surface .... Concrete Tarmac
- Vehicle Make/Model .... 2009 Dodge Ram 1500 quad cab pickup truck
    - Curb .... 5,084 lb (2,306 kg)
    - Test Inertial .... 5,001 lb (2,268 kg)
    - Gross Static .... 5,162 lb (2,341 kg)
- Impact Conditions
    - Speed .... 62.7 mph (100.8 km/h)
    - Angle .... 24.9 deg
    - Impact Location .... $49^{7}/_{16}$ in. (1.26 m) upstream from joint 4-5
- Impact Severity .... 116.3 kip-ft (157.7 kJ) > 105.6 kip-ft (143.1 kJ) limit in MASH 2016
- Exit Conditions
    - Speed .... 48.9 mph (78.7 km/h)
    - Angle .... 4.9 deg
    - Exit Box Criterion .... Pass
- Vehicle Stability .... Satisfactory
- Test Article Damage .... Moderate
- Vehicle Stopping Distance .... 234 ft – 11 in. (71.6 m) downstream
  48 ft – 10 in. (14.9 m) laterally in front
- Vehicle Damage .... Moderate
    - VDS [14] 11-LFQ-4
    - CDC [15] 11-LYEW-4
    - Maximum Interior Deformation .... 1¾ in. (44 mm)
- Maximum Test Article Deflections
    - Permanent Set .... 32½ in. (826 mm)
    - Dynamic .... 33.0 in. (838 mm)
    - Working Width .... 57.0 in. (1,448 mm)
- Transducer Data

Evaluation Criteria		Transducer SLICE-2 (primary)	Transducer DTS	MASH 2016 Limit
OIV ft/s (m/s)	Longitudinal	-13.61 (-4.15)	-13.17 (-4.02)	± 40 (12.2)
	Lateral	21.62 (6.59)	18.33 (5.59)	± 40 (12.2)
ORA g's	Longitudinal	-7.65	-7.13	± 20.49
	Lateral	9.62	11.15	± 20.49
MAX .ANGULAR DISP. deg.	Roll	-7.9	-8.2	± 75
	Pitch	-12.5	-12.2	± 75
	Yaw	42.4	45.0	Not required
THIV – ft/s (m/s)		26.44 (8.06)	21.75 (6.63)	Not required
PHD – g's		9.72	11.21	Not required
ASI		1.41	1.25	Not required

Figure 26. Summary of Test Results and Sequential Photographs, Test No. NJPCB-5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1.518 sec


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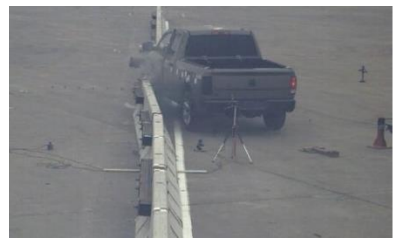
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Figure 27. Additional Sequential Photographs, Test No. NJPCB-5


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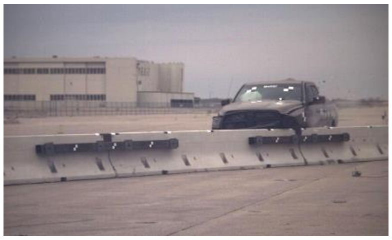
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Figure 28. Additional Sequential Photographs, Test No. NJPCB-5

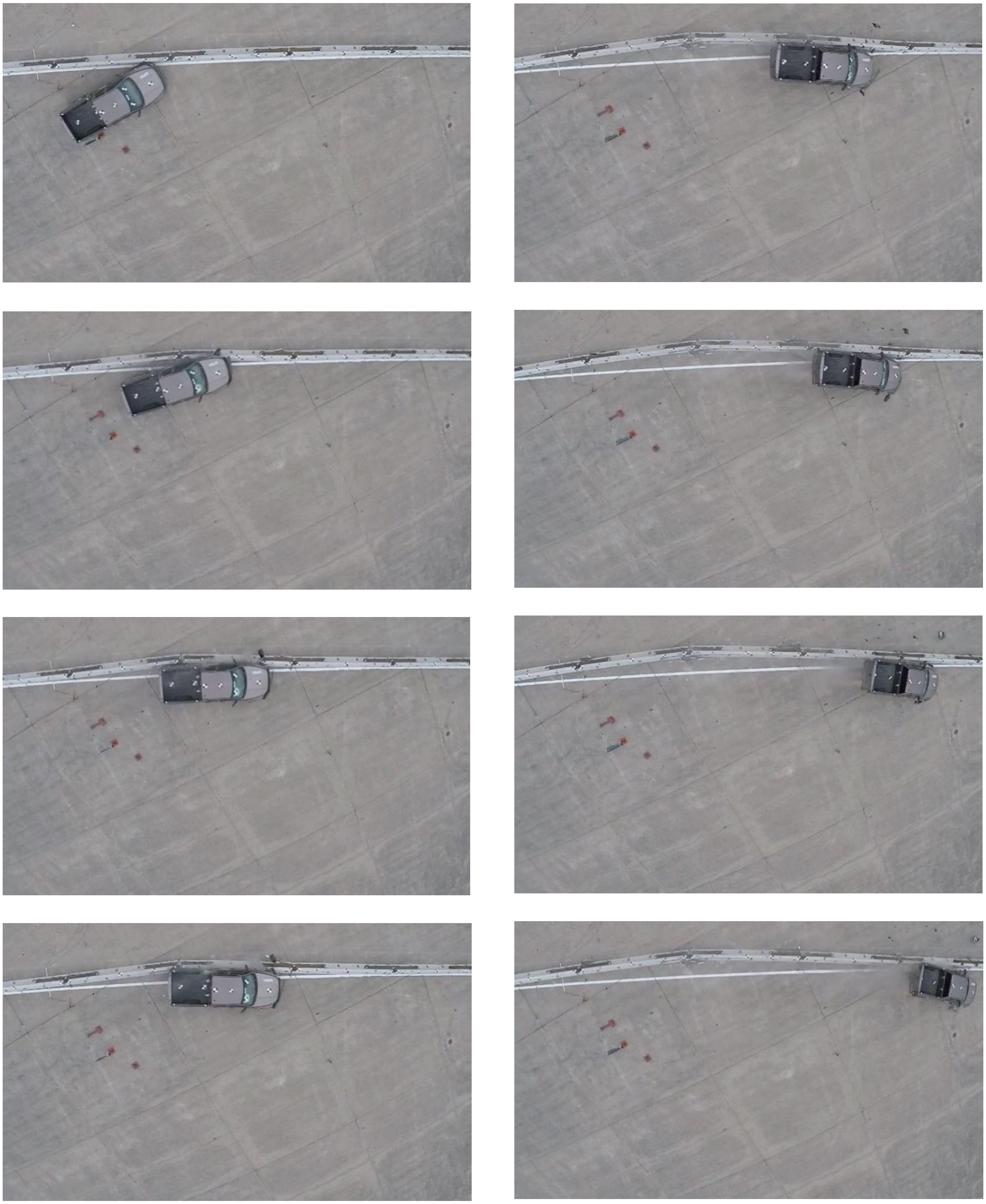


Figure 29. Documentary Photographs, Test No. NJPCB-5

Figure 30. Documentary Photographs, Test No. NJPCB-5

Figure 31. Documentary Photographs, Test No. NJPCB-5

Figure 32. Documentary Photographs, Test No. NJPCB-5

Figure 33. Impact Location, Test No. NJPCB-5

Figure 34. Vehicle Final Position and Trajectory Marks, Test No. NJPCB-5

Figure 35. System Damage - Front, Back, Upstream, and Downstream Views, Test No. NJPCB-5

Figure 36. System Damage at Impact Location, Front and Back Side, Test No. NJPCB-5

Figure 37. Barrier No. 2 – Traffic and Back Side Damage, Test No. NJPCB-5

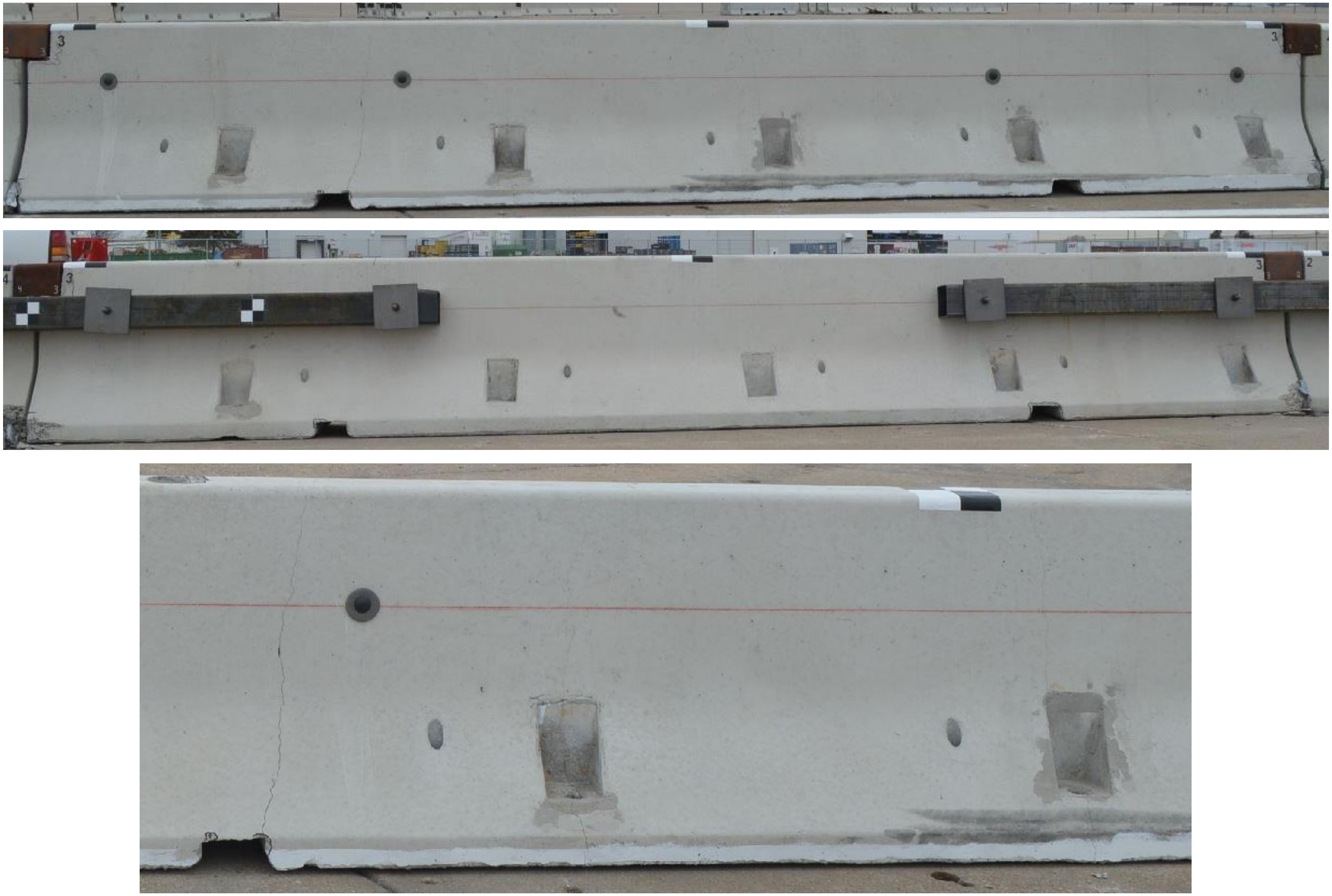


Figure 38. Barrier No. 3 – Traffic and Back Side Damage, Test No. NJPCB-5

Figure 39. Barrier No. 4 – Traffic and Back Side Damage, Test No. NJPCB-5

Figure 40. Barrier No. 5 – Traffic and Back Side Damage, Test No. NJPCB-5

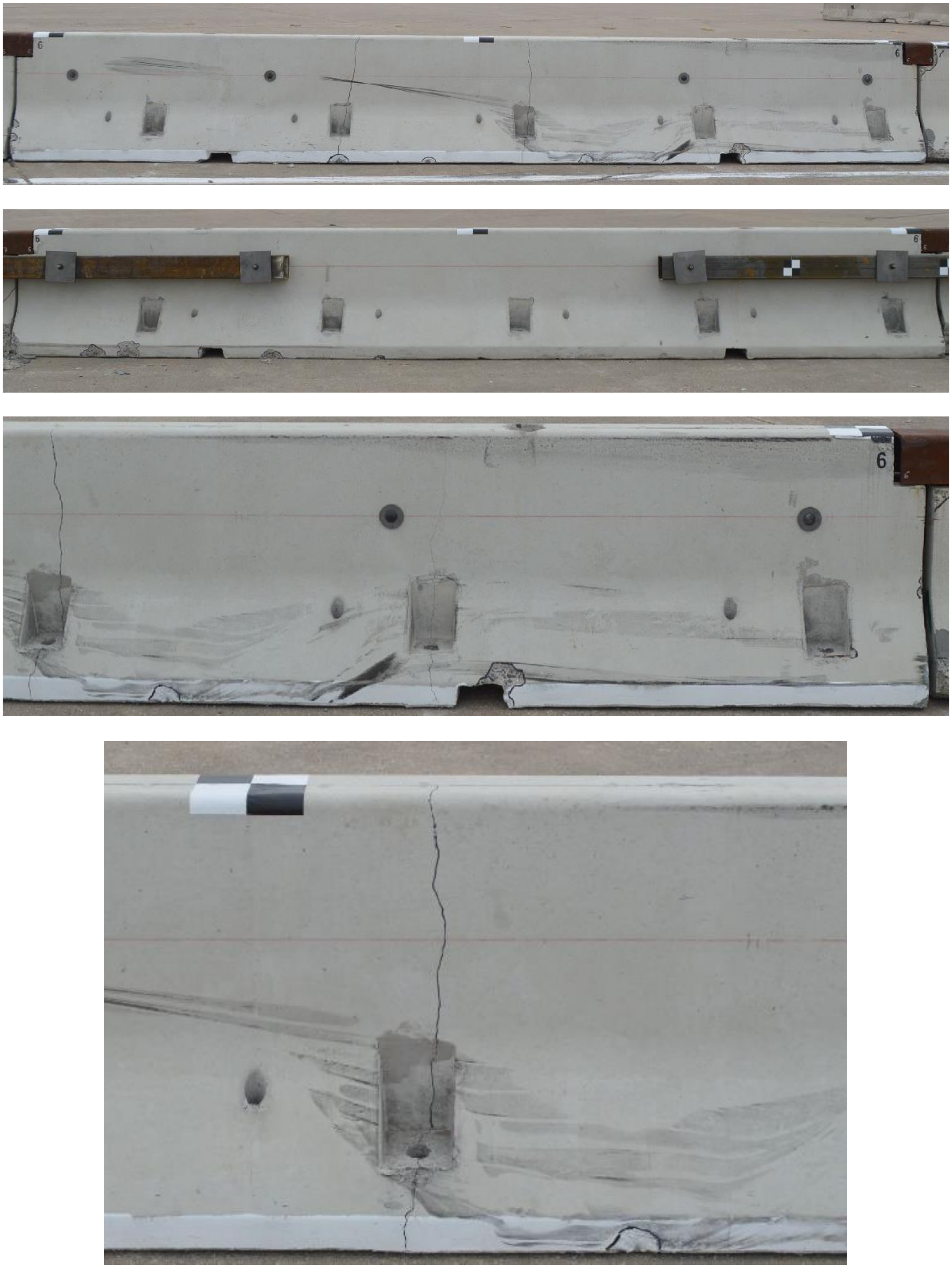


Figure 41. Barrier No. 6 – Traffic and Back Side Damage, Test No. NJPCB-5

Figure 42. Barrier No. 7 – Traffic and Back Side Damage, Test No. NJPCB-5

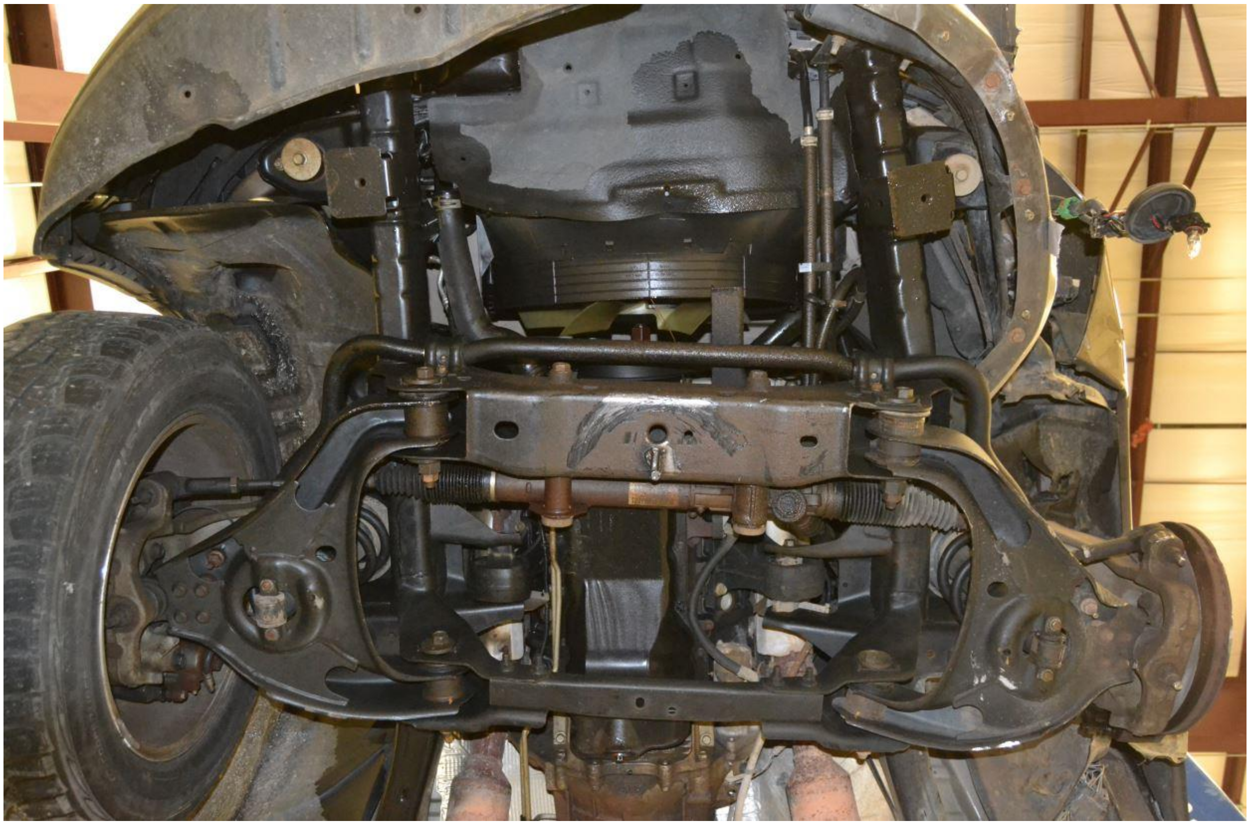
Figure 43. Barrier No. 8 – Traffic and Back Side Damage, Test No. NJPCB-5

Figure 44. Vehicle Damage, Test No. NJPCB-5

Figure 45. Vehicle Damage on Impact Side, Test No. NJPCB-5

Figure 46. Vehicle Windshield Damage, Test No. NJPCB-5

Figure 47. Occupant Compartment Deformation, Test No. NJPCB-5



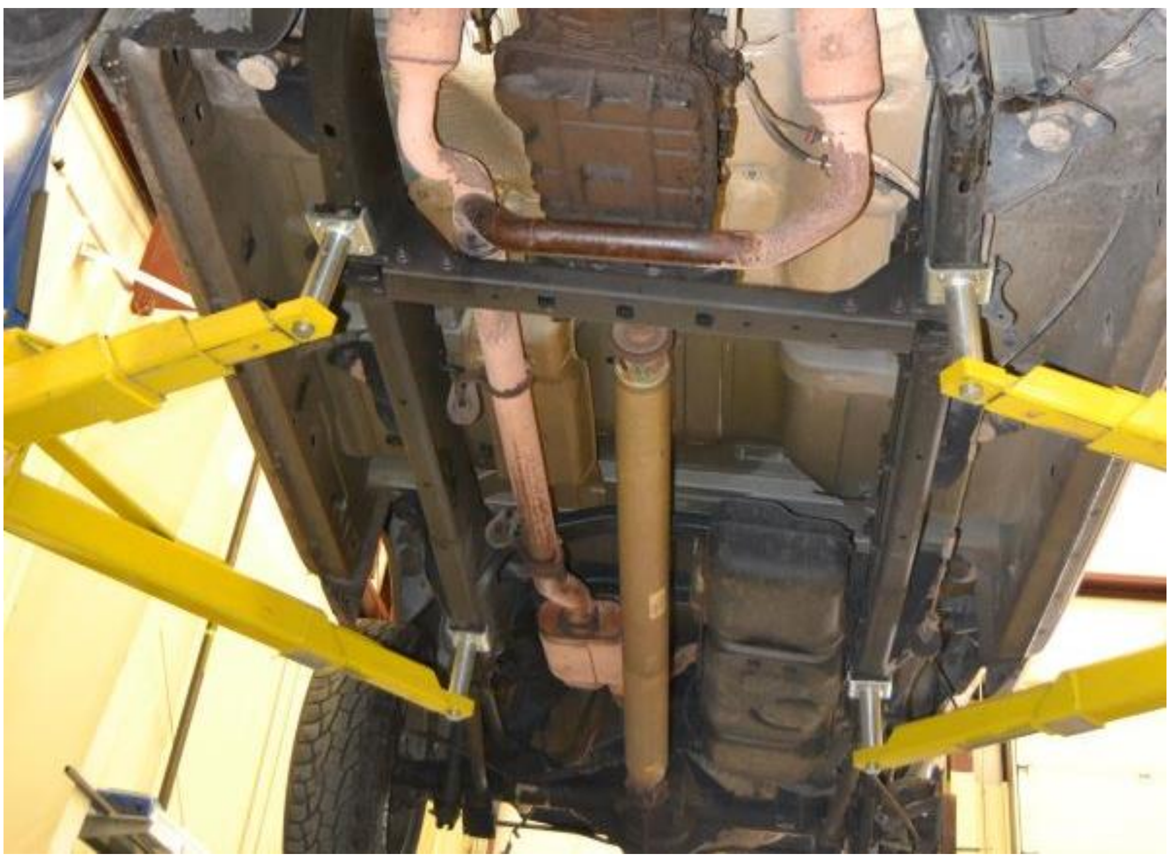


Figure 48. Undercarriage Damage, Test No. NJPCB-5

6 SUMMARY AND CONCLUSIONS

Test no. NJPCB-5 was conducted on the NJDOT PCB system with a box-beam stiffened configuration and grouted toes according to MASH 2016 test designation no. 3-11. This system uses NJDOT barriers, Type 4 (Alternative B) with connection type B, as specified in the 2015 NJDOT *Roadway Design Manual*. Barrier nos. 1 and 10 were anchored to the concrete tarmac through nine pin anchor recesses with 1-in. (25-mm) diameter by 15-in. (381-mm) long ASTM A36 steel pins. The nine joints between barrier nos. 1 through 10 were stiffened with box beam rails. Each box-beam stiffener was a 12-ft (3.7-m) long, 6-in. × 6-in. × $^{3}/_{16}$-in. (152-mm × 152-mm × 5-mm) ASTM A500 Grade C box beam. The box-beam stiffeners were connected to the barriers with ¾-in. (19-mm) diameter by 17-in. (432-mm) long ASTM A307 Grade A bolts without square necks and ¾-in. (19-mm) diameter ASTM A563A nuts. Non-shrink grout wedges were placed at the toe of each barrier segment in every joint between adjacent barrier segments on both the traffic and back sides.

During test no. NJPCB-5, the 5,001-lb (2,268 kg) pickup truck impacted the NJDOT PCB system at a speed of 62.7 mph (100.8 km/h) and at an angle of 24.9 degrees, resulting in an impact severity of 116.3 kip-ft (157.7 kJ). After impacting the barrier system, the vehicle exited the system at a speed of 48.9 mph (78.7 km/h) and at an angle of 4.9 degrees. The vehicle was successfully contained and smoothly redirected with moderate damage to both the barrier and the vehicle. Barrier nos. 4 and 5 experienced concrete spalling and cracking. A dynamic deflection of 33.0 in. (838 mm) and a working width of 57.0 in. (1,448 mm) were observed during the test, as shown in Figure 25. All occupant risk values were found to be within limits, and the occupant compartment deformations were also deemed acceptable. Subsequently, test no. NJPCB-5 was determined to satisfy the safety performance criteria for MASH 2016 test designation no. 3-11. A summary of the test evaluation is shown in Table 9.

Table 9. Summary of Safety Performance Evaluation

<table>
<tr><th>Evaluation Factors</th><th colspan="2">Evaluation Criteria</th><th>Test No. NJPCB-5</th></tr>
<tr><td>Structural Adequacy</td><td>A.</td><td>Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td><td>S</td></tr>
<tr><td rowspan="5">Occupant Risk</td><td rowspan="2">D.</td><td>1. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.</td><td>S</td></tr>
<tr><td>2. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH 2016.</td><td>S</td></tr>
<tr><td>F.</td><td>The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td><td>S</td></tr>
<tr><td>H.</td><td>Occupant Impact Velocity (OIV) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:
<table>
<tr><th colspan="3">Occupant Impact Velocity Limits</th></tr>
<tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr>
<tr><td>Longitudinal and Lateral</td><td>30 ft/s (9.1 m/s)</td><td>40 ft/s (12.2 m/s)</td></tr>
</table></td><td>S</td></tr>
<tr><td>I.</td><td>The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:
<table>
<tr><th colspan="3">Occupant Ridedown Acceleration Limits</th></tr>
<tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr>
<tr><td>Longitudinal and Lateral</td><td>15.0 g’s</td><td>20.49 g’s</td></tr>
</table></td><td>S</td></tr>
<tr><td colspan="3">MASH 2016 Test Designation No.</td><td>3-11</td></tr>
<tr><td colspan="3">Final Evaluation (Pass or Fail)</td><td>Pass</td></tr>
</table>

S – Satisfactory U – Unsatisfactory NA - Not Applicable

7 COMPARISON TO TEST NO. NYTCB-1

A summary of full-scale crash testing on one NJ PCB system (test no. NJPCB-5) and one New York PCB system (test no. NYTCB-1) [16], which used 6-in. x 6-in. x $^{3}/_{16}$-in. (152-mm x 152-mm x 5-mm) box beam bolted across the back side of barrier segment joints to increase barrier stiffness and reduce PCB deflections, is shown in Table 10. The only difference between the two crash-tested systems was that the New York system had box-beam only bolted across the barrier joints from barrier nos. 4 through 7, while the New Jersey system had box-beam bolted across all barrier joints. Results from these tests included the actual impact conditions and impact severity as well as dynamic barrier deflection, permanent set barrier deflection, working width (as measured from the original front face of the barrier), and the clear space behind the barrier. The clear space behind the barrier is used by NJDOT to define the maximum deflection of the back of the barrier from its original position. In addition, the schematic diagrams shown in Figure 49 indicate how the dynamic deflection, permanent set deflection, and working width for each crash test was defined.

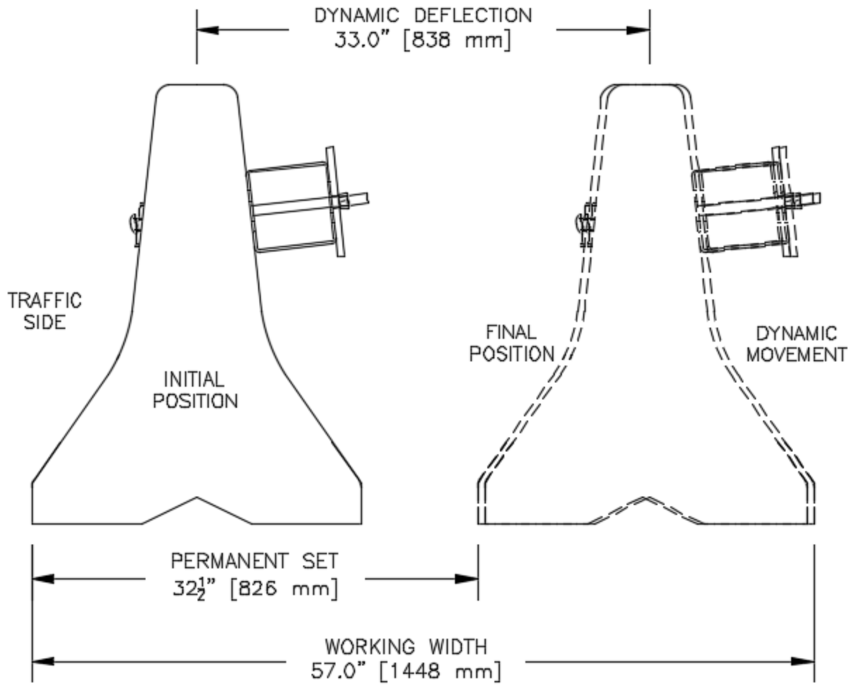
A review of the results from test nos. NJPCB-5 and NYTCB-1 revealed little to no benefit in terms of barrier deflection and clear space requirements for box-beam stiffened PCBs due to removal of joint slack and/or the use of grouted barrier toes. This finding was evidenced in the slight increase in barrier deflections and clear space observed in the New Jersey crash test with removal of joint slack and use of grouted toes. The smaller observed benefit for the modified PCB joints was correlated with limited barrier reinforcement in the toes of both the New York and New Jersey PCB segments. The lack of reinforcement led to fracture of the barrier toes when they were loaded by adjacent barrier segments, which caused increased rotation and motion of the barrier joints. This concrete toe disengagement reduced the expected benefit that would have been provided by the removal of joint slack and use of grouted toes. Instead, similar joint rotation and displacement was observed for both the New Jersey and New York PCB crash tests. Secondly, the PCB segments used in these tests have a relatively small gap between adjacent barrier segments. Thus, improvement of the joint response through removal of joint slack and use of grouted toes provided less benefit than would be expected for other PCB systems, which utilize joint spacings up to 4 inches. Finally, barrier system behavior and associated barrier deflections can vary from test to test due to the natural variability of a wide variety of factors involved in full-scale crash testing. These factors would include slight differences in impact conditions (e.g., slight increased impact severity value in test no. NJPCB-5), differing test vehicle model years, slight variations in steel and concrete strengths, and variation of the cracking and damage observed on the barrier segment, among others. Thus, some variability would be expected in barrier performance even for basically identical systems.

Smaller reductions in PCB deflections and clear space behind the barrier were observed with the removal of joint slack and use of grouted toes. This finding was primarily due to the fracture and disengagement of the barrier toes. If larger reductions in PCB deflections and clear space are desired, PCB redesign or modification would be required, including the reinforcement of the barrier toes, which may improve the effectiveness of joint slack removal and the use of grouted toes.

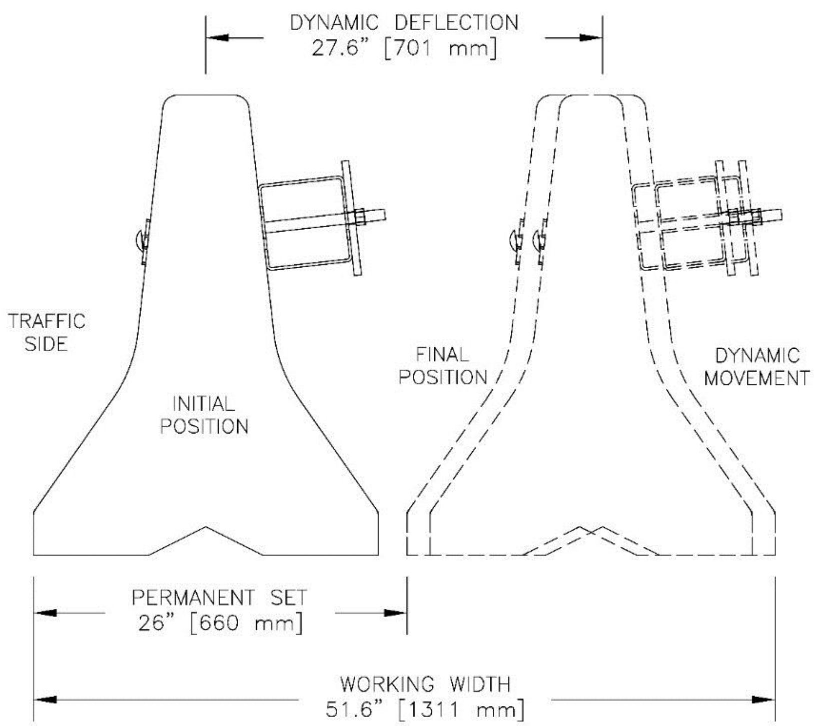
Table 10. Comparison of 6-in. x 6-in. x $^{3}/_{16}$-in. (152-mm x 152-mm x 5-mm) Box-Beam Stiffened Systems

Test No.	Connection Type [2]	System Details	Permanent Set	Dynamic Deflection (DD)	Working Width (WW)	Clear Space Behind Barrier	Vehicle Roll (deg)	Vehicle Pitch (deg)	Vehicle Mass lb (kg)	Impact Speed mph (km/h)	Impact Angle (deg)	Impact Severity kip-ft (kJ)
NJPCB-5	B	Free-standing system, barriers 1 and 10 pinned, box-beam stiffened all joints (8 joints), remove slack, grouted toes	32½ in. (826 mm)	33.0 in. (838 mm)	57.0 in. (1,448 mm)	33.0 in. (838 mm)	-7.9	-12.5	5,001 (2,268)	62.7 (100.8)	24.9	116.3 (157.7)
NYTCB-1 [16]	N/A	Free-standing system, barriers 1 and 10 pinned, box-beam stiffened 3 joints (4-7), slack not removed, no grouted toes	26 in. (660 mm)	27.6 in. (700 mm)	51.6 in. (1,311 mm)	27.6 in. (700 mm)	-10.5	-11.4	5,016 (2,275)	61.9 (99.5)	24.6	111.3 (151.0)

N/A = Not Applicable



(a) NJPCB-5 – Free-Standing, Joint Slack Removed, Grouted Toes, Box-Beam Stiffened All Joints



(b) NYTCB-1 – Free-Standing, Joint Slack Not Removed, No Grouted Toes, Box-Beam Stiffened 3 Joints

Figure 49. Deflection Comparisons – (a) Test Nos. NJPCB-5 and (b) NYTCB-1

8 LS-DYNA MODEL OF NJDOT PCB SYSTEMS

8.1 Introduction

NJDOT desired to further evaluate shorter system lengths for the PCB with a box-beam stiffened configuration, corresponding to connection type B in the 2015 NJDOT *Roadway Design Manual*. Finite element modeling is a useful method to evaluate and analyze roadside safety hardware and was utilized for this effort. LS-DYNA is a nonlinear, transient, dynamic, finite element analysis code and has been widely used to evaluate vehicle and roadside safety hardware impacts [17]. Two finite element barrier models were developed using LS-DYNA: a free-standing configuration similar to crash test no. NJPCB-3 [18] and a box-beam stiffened configuration similar to crash test no. NJPCB-5.

The methodology for evaluating the performance of the PCBs is based on a baseline simulation model of the New Jersey-shaped PCB system in the 200-ft (61.0-m) long, free-standing configuration, which corresponds to the system tested in full-scale crash test no. NJPCB-3 according to MASH 2009 test designation no. 3-11. Next, a simulation model of the box-beam stiffened PCB system was developed and validated with full-scale crash test no. NJPCB-5. In both of these crash tests, the end barrier segments (barrier nos. 1 and 10) had nine pins constraining the barrier to the concrete foundation. The reduced-deflection system incorporated 12-ft (3.7-m) long, box-beam stiffeners spanning all barrier system joints on the 200-ft (61.0-m) long system with non-shrink grout at the toes of the barriers. The computer simulation results were compared with the physical crash test results obtained from test nos. NJPCB-3 and NJPCB-5 to ensure the feasibility of this model to provide reasonable estimates of barrier deflections and safety performance. Several results were compared, including damage, deflections, velocities, angular displacements, and overall behavior. After the barrier models produced reasonable results, additional simulations were conducted with 160-ft (48.8-m), 120-ft (36.6-m), and 100-ft (30.5-m) long, box-beam stiffened, PCB systems to estimate barrier deflections and safety performance at reduced system lengths.

8.2 Free-Standing PCB Model (NJPCB-3)

The finite element model of the New Jersey-shape PCB was based on the NJDOT PCB in a free-standing configuration that was crash tested and evaluated to MASH 2009 TL-3. The concrete barrier system was comprised of ten 20-ft (6.1-m) long PCB sections with a total system length of 200 ft (61.0 m). The model consisted of reinforced concrete barriers, connection key sockets, and connection keys, as shown in Figure 50.

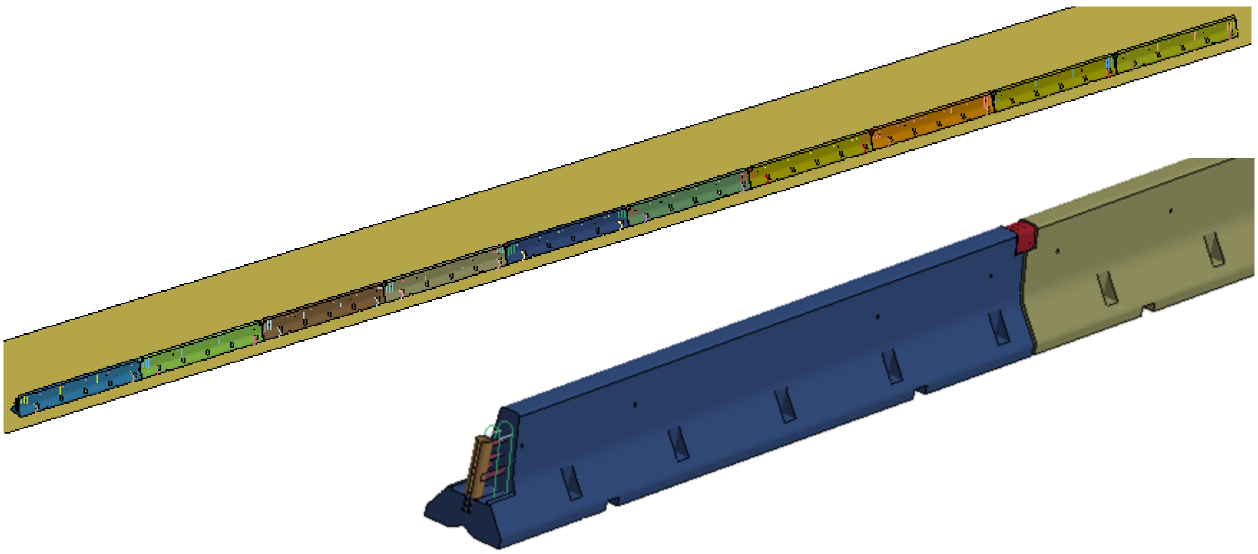
In order to represent the real behavior of a dynamic impact on a concrete barrier, the barrier was developed with three primary components – concrete, steel reinforcement, and end connection hardware. The concrete component of the barrier was created using eight-node constant stress solid brick elements. The concrete was modeled using the MAT_CSCM_CONCRETE material model, which is a smooth continuous surface cap model developed and validated by the Federal Highway Administration to predict the dynamic behaviors of the concrete in roadside safety hardware under vehicle collision. According to NJDOT standards, the minimum compressive strength of concrete was specified as 3,700 psi (25.5 MPa). However, the concrete barriers provided an average compressive strength around 7,300 psi (50 MPa) according to the supplied material certifications. In the material model, the concrete compressive strength was specified as 7,300 psi (50 MPa). A value of 10 was specified for the Recov parameter. The Recov parameter defines the recovery stiffness modulus when switching between compression and tension within an element and attempts to model crack closing in concrete. When Recov is 10 or greater, a flag is internally set to base stiffness recovery on volumetric strain as well as pressure. According to the prior research [19-20] and many computation trials, a value of 10 produced reasonably accurate results for a vehicle impacting a PCB.

The two-node Hughes-Liu beam element was utilized for the reinforcement due to its simple and efficient computation and compatibility with the solid brick element. In the reinforcement beam element, the outer diameter corresponded to the diameter of the reinforcement bar, while an inner diameter of zero was defined. The steel reinforcing bars that were embedded into the concrete were modeled with the MAT_PIECEWISE_LINEAR_PLASTICITY material in LS-DYNA with properties for ASTM A615 Grade 60 steel.

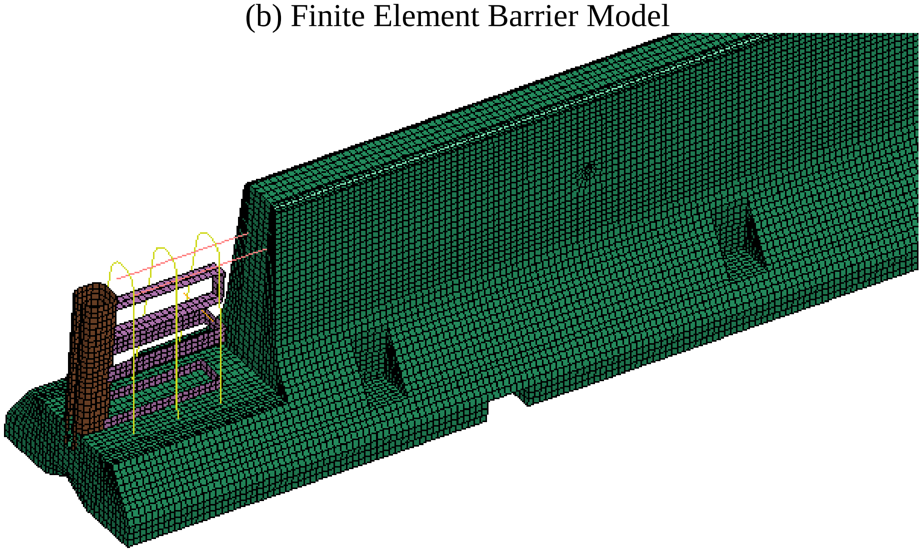
The CONSTRAINED_LAGRANGE_IN_SOLID keyword in LS-DYNA was used to embed the reinforcement beam elements into the concrete brick elements. The slave set (reinforcement) is coupled to the master set (concrete). The keyword constrains the slave beam set (reinforcement) to move with master Lagrangian solids (concrete). This keyword has been utilized previously and has demonstrated accuracy and efficiency in embedding reinforcement beam elements into the concrete brick elements [19, 21].

Four-noded Hughes-Liu type shell elements were used to create the connection key sockets and the connection keys. The shell elements of connection key sockets were merged with the concrete brick elements. Therefore, the contact between the connection key socket and the concrete was assumed as a perfect bond. The shell elements are coincident with the concrete elements, as shown in Figure 51. The steel connection key socket was modeled using the MAT_PIECEWISE_LINEAR_PLASTICITY material with properties of ASTM A500 Grade B steel. The material properties for ASTM A36 steel were utilized to model the connection key. Strain rate effects for the steel material model were considered with the Cowper Symonds model by defining strain rate parameters C and P with the value of 40 and 5, respectively. All required parameters, including the yield strength, modulus of elasticity, and plastic strain-yield stress values, were determined based on the material certifications from test no. NJPCB-3. The simulation model parts and associated LS-DYNA modeling parameters are shown in Table 6.

(a) As-Tested Barrier System (Test No. NJPCB-3)



(b) Finite Element Barrier Model



(c) Barrier and Reinforcement Mesh (Concrete Section Hidden)

Figure 50. Free-Standing PCB Baseline Model

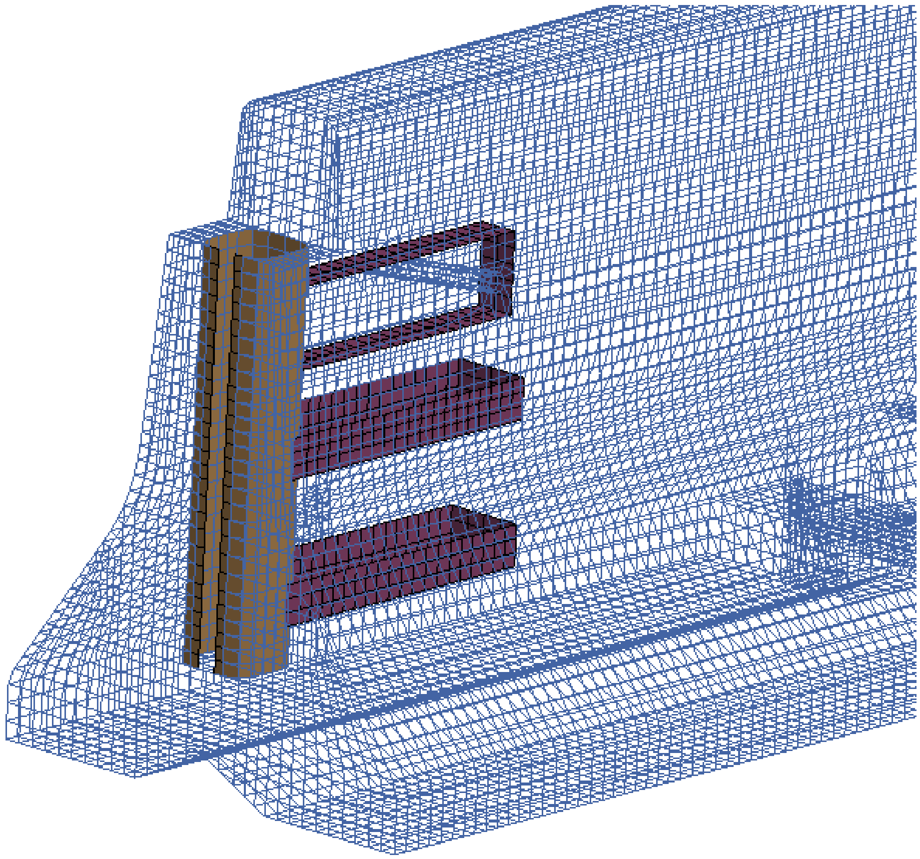


Figure 51. Steel Component Shell Elements Coinciding with Concrete Elements

Table 11. List of Simulation Model Parts and LS-DYNA Parameters

Part Name	Element Type	Element Formulation	Material Type	Material Formulation
Concrete Barrier	Solid	Constant stress	7,300 psi (50 MPa) Concrete	CSCM Concrete
Reinforcement	Beam	Hughes-Liu	ASTM A615 Steel	Piecewise, Linear Plasticity
Connection Key Socket Tube	Shell	Belytschko-Tsay	ASTM A500 Steel	Piecewise, Linear Plasticity
Connection Key Socket Plate	Shell	Belytschko-Tsay	ASTM A36 Steel	Piecewise, Linear Plasticity
Connection Key	Shell	Belytschko-Tsay	ASTM A36 Steel	Piecewise, Linear Plasticity

The two end barriers in the model were constrained similarly to the pinned condition in the full-scale crash tests. In test no. NJPCB-3, barrier no. 1 deflected 0 in. (0 mm) laterally and ⅜ in. (9.5 mm) longitudinally, and barrier no. 10 deflected 0 in. (0 mm) laterally and 0 in. (0 mm) longitudinally. In test no. NJPCB-3, barrier nos. 1 and 10 had negligible deflection in the lateral and longitudinal directions. Since the end barriers moved minimally in the crash tests, the pins were not explicitly modeled, and the pin hole locations in the model were prescribed single point constraints constraining motion in the x- and y- directions (lateral and longitudinal), as shown in Figure 52.

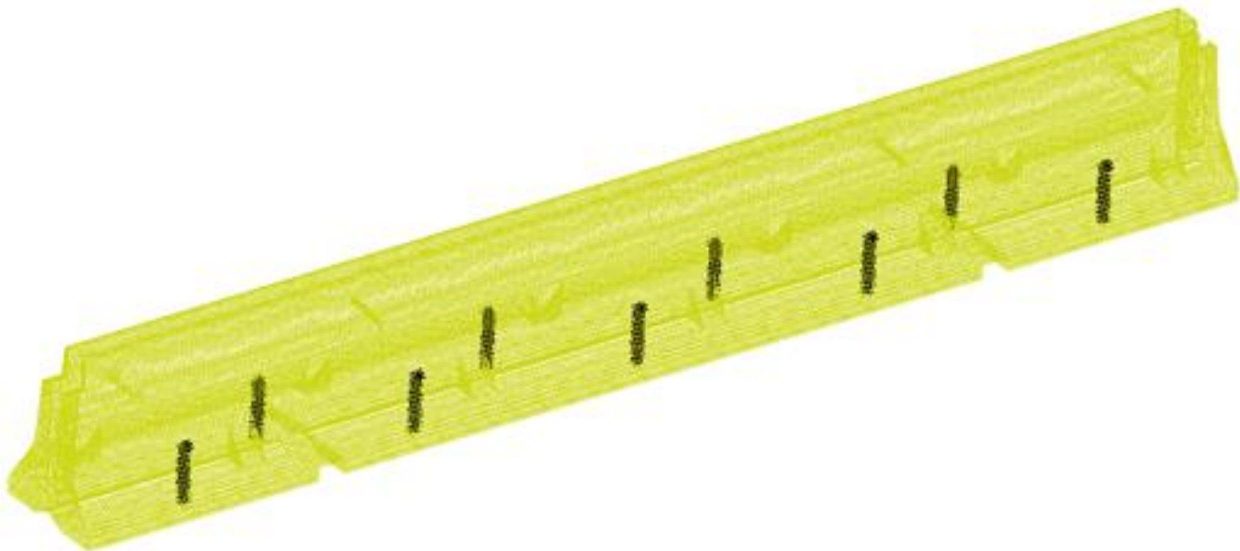


Figure 52. Pinned Locations and Point Constraints

The contact among the concrete barriers, the connection key sockets, and the connection keys were modeled as the segment-based contact using CONTACT_AUTOMATIC_ SINGLE_SURFACE. The contact between the concrete barriers and the vehicle was defined using the segment-based contact with CONTACT_AUTOMATIC_SURFACE_TO_SURFACE in LS-DYNA. A static and dynamic coefficient of friction of 0.1 was utilized for the vehicle and barrier contact, which has been commonly used in prior concrete barrier models.

For the model of the free-standing PCBs, the longitudinal tension is a critical component to be considered. The PCBs redirect impacting vehicles based on a combination of inertial resistance and longitudinal tension. In order to accurately model barrier deflection and damage, the barrier-to-ground friction needs to be accurate. Many computation trials were conducted, and a kinematic friction coefficient between the PCB segments and the ground of 0.2 was applied to predict the realistic behavior of the barriers obtained in the test. Damping was defined initially to allow the barriers in the finite element model to reach a steady normal force on the ground, but was terminated before vehicle impact.

8.3 Box-Beam Stiffened PCB Model (NJPCB-5)

A finite element model of crash test no. NJPCB-5 with box-beam stiffeners and grouted toes was developed to provide further verification of the PCB model, as shown in Figure 53. The model of crash test no. NJPCB-5 was developed based on the same PCB model created to serve as a baseline model for crash test no. NJPCB-3, described previously.

The tubes on the back side of the barrier and the back washer were added using Belytschko-Tsay shell elements. The bolts, nuts, and front washers were modeled using constant stress solid brick elements. The steel material properties of all steel components were defined using the MAT_PIECEWISE_LINEAR_PLASTICITY material model. The bolts, nuts, and washers had properties similar to ASTM A307 steel, and the tube had properties similar to ASTM A500 Gr. B steel. The tubes were connected to the barriers using several bolts, similar to the system in crash test no. NJPCB-5. Bolt preload was achieved using the keyword INITIAL_STRESS_SECTION.

Grout was utilized in the as-tested PCB system for crash test no. NJPCB-5 and was modeled with constant stress solid elements and a MAT_ELASTIC material model. Grout placed at the toes between the barrier segments had similar compressive properties and geometry as that utilized in crash test no. NJPCB-5. However, the modelled grout was not bonded to the concrete barrier models, and could disengage when in tension. In the full-scale crash test, the grout typically remained attached to one barrier end and fractured off of the adjacent barrier end.

A list of simulation model parts and associated LS-DYNA modeling parameters are shown in Table 12. The contact in the components of the connection hardware, including the barriers, bolts, nuts, washers, and grout, was defined as a segment-based contact using CONTACT_ AUTOMATIC_SINGLE_SURFACE.

Table 12. List of Simulation Model Parts and LS-DYNA Parameters

Part Name	Element Type	Element Formulation	Material Type	Material Formulation
Concrete Barrier	Solid	Constant stress	7,300 psi (50 MPa) Concrete	CSCM Concrete
Reinforcement	Beam	Hughes-Liu	ASTM A615	Piecewise, Linear Plasticity
Connection Key Socket	Shell	Belytschko-Tsay	ASTM A500	Piecewise, Linear Plasticity
Connection Key	Shell	Belytschko-Tsay	ASTM A36	Piecewise, Linear Plasticity
Bolts	Solid	Constant stress	ASTM A307	Piecewise, Linear Plasticity
Nuts	Solid	Constant stress	ASTM A307	Piecewise, Linear Plasticity
Front Washer	Solid	Constant stress	ASTM A307	Piecewise, Linear Plasticity
Back Washer Plate	Shell	Belytschko-Tsay	ASTM A36	Piecewise, Linear Plasticity
Tube	Shell	Belytschko-Tsay	ASTM A500	Piecewise, Linear Plasticity
Grout	Solid	Constant stress	Non-shrink grout	Elastic

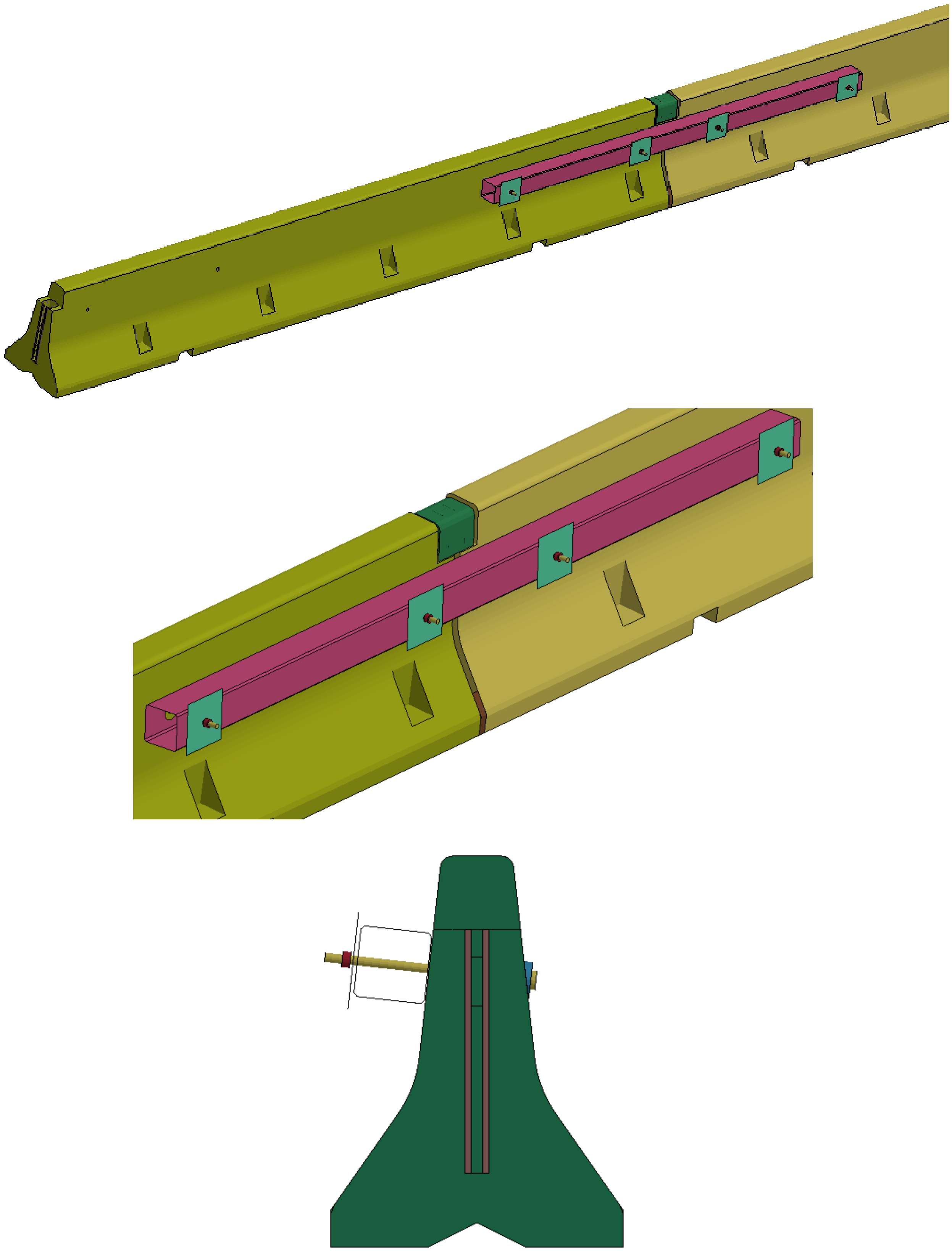


Figure 53. Box-Beam Reduced-Deflection PCB Baseline Model

9 BASELINE AND REDUCED-LENGTH SIMULATIONS

9.1 Simulation of Crash Test No. NJPCB-3

The vehicle model used for the simulation was the Version 3, reduced-element, Chevrolet Silverado model developed at the National Crash Analysis Center (NCAC), and modified by MwRSF researchers for roadside safety applications [22]. In crash test no. NJPCB-3, a Dodge Ram pickup truck impacted the free-standing PCB system at a speed of 62.3 mph (100.2 km/h) and at an angle of 25.8 degrees. In the simulation of crash test no. NJPCB-3, the Chevy Silverado pickup truck model impacted the PCB model at a speed of 62.1 mph (100.0 km/h) and at an angle of 25 degrees. Initial vehicle impact was to occur 51$^{3}/_{16}$ in. (1.3 m) upstream from the centerline of the joint between barrier nos. 4 and 5, as shown in Figure 54, which was modeled. The actual impact point in crash test no. NJPCB-3 was 46$^{3}/_{16}$ in. (1.2 m) upstream from the centerline of the joint between barrier nos. 4 and 5.

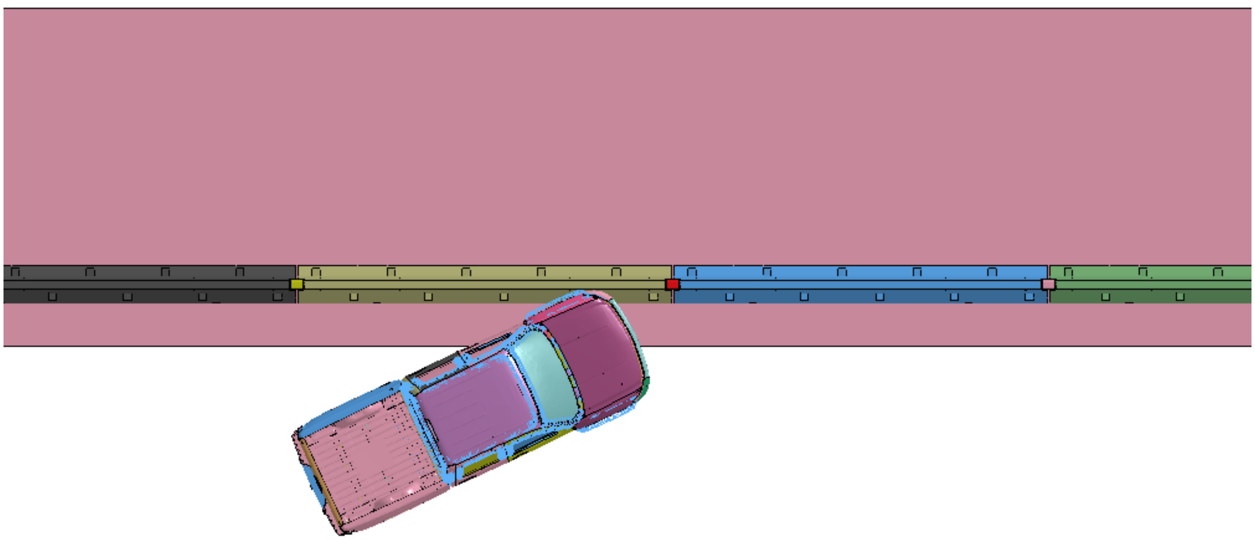


Figure 54. Model of Crash Test No. NJPCB-3 Impact Point

Graphical comparisons of the results from both the simulation and crash test no. NJPCB-3, as shown in Figures 55 through 60, showed that the behavior of the vehicle and the barrier in the simulation matched reasonably well with the full-scale crash test. However, there was a noticeable difference in vehicle roll after 70 ms and pitch after 250 ms, as shown in Figures 56, 57, and 61. These differences are believed to be due to inaccuracies in vehicle tire, suspension, and steering models, as well as friction. The selected vehicle model does not have failure in the suspension or steering components, and the tires are much stiffer than observed in an actual vehicle. Further, refinement of these components would require a significant research effort, which was outside the scope of this project. As shown in Figures 56 and 57, the right-front tire in the simulation turns toward the right (passenger side) very shortly after impact, which does not happen in the actual test. This behavior is believed to be due to the tire's stiffness and lack of suspension failure and steering in the vehicle model. This behavior likely also leads to differences in the vehicle roll and pitch later in the impact event. However, these differences did not affect the redirection of the vehicle and are believed to minimally affect the loading and displacement of the barriers.

Comparison of barrier damage between the simulation and crash test no. NJPCB-3, as shown in Figures 58 through 60, demonstrated that the barrier damage in the baseline model agreed well with full-scale test no. NJPCB-3. Stress plots are shown for some of the simulation photos. Areas of blue indicated no stress and areas of red indicated high stress areas where a crack formed or was about to form. Minor cracking occurred on barrier nos. 3, 6, 7, and 8. More significant vertical cracks were found on the front and back faces of barrier nos. 4 and 5. Concrete spalling occurred on barrier nos. 3 through 8. Several pieces of concrete were disengaged from the front and back faces of barrier nos. 4 and 5.

A comparison of the dynamic deflection between crash test no. NJPCB-3 and the simulation is shown in Table 13. In both crash test no. NJPCB-3 and the simulation, the impacted barrier segments rotated slightly backward. The maximum dynamic deflection of the simulated barrier was determined to be 42.5 in. (1,080 mm) at the downstream end of the fourth barrier segment, as compared to the dynamic deflection of crash test no. NJPCB-3, which was measured to be 38.1 in. (968 mm) at the downstream end of the fourth barrier segment. The simulated barrier displacement was 10 percent higher than the displacement observed in the full-scale crash test. Differences of up to 20 percent are usually considered acceptable when comparing displacements from simulations and full-scale crash tests.

Comparisons between longitudinal and lateral changes in velocity and Euler angular displacements of the simulation and crash test no. NJPCB-3 are shown in Figure 61. The differences in the longitudinal change in velocity and roll were greatest, which is partially due to the behavior of the impact-side front tire, as described previously, as well as frictions between the sheet metal, rubber, and barriers. Also, the rear axle of the Chevrolet Silverado model is stiffer than observed for actual pickup truck axle behavior. Thus, the lateral tail slap event in simulations always produces a greater impact force due to the way it is modelled, which also explains the greater variation in the changes in velocity and Euler angular displacements after 200 ms.

Based on the comparison, the simulation provided reasonable estimates of barrier deflection and damage under MASH TL-3 impact conditions. While some differences existed between the simulation and the crash test, the research team felt that accurate deflections and safety performance could still be estimated from the simulations. The differences were considered throughout the analysis, and the model limitations are further discussed in Section 9.3.

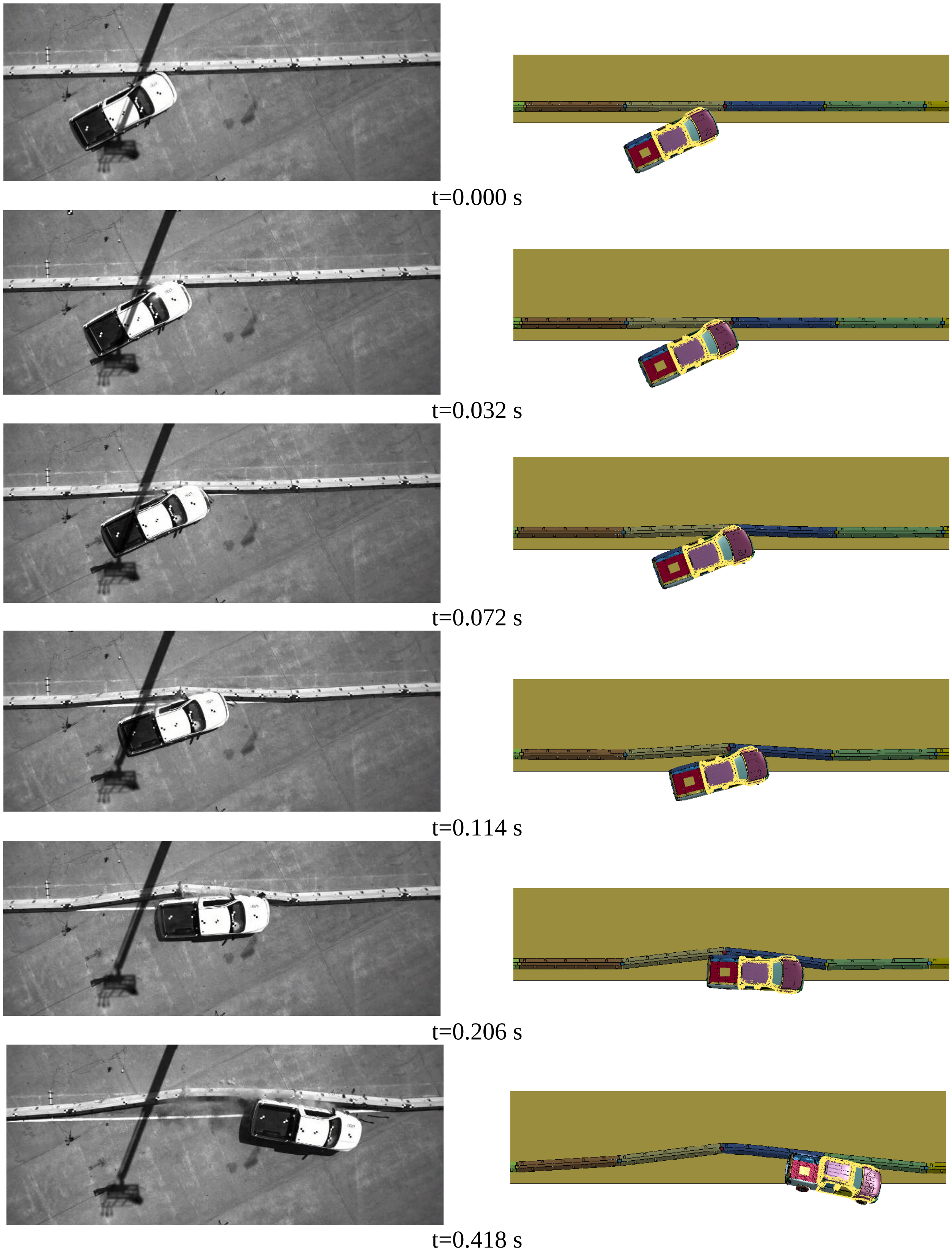
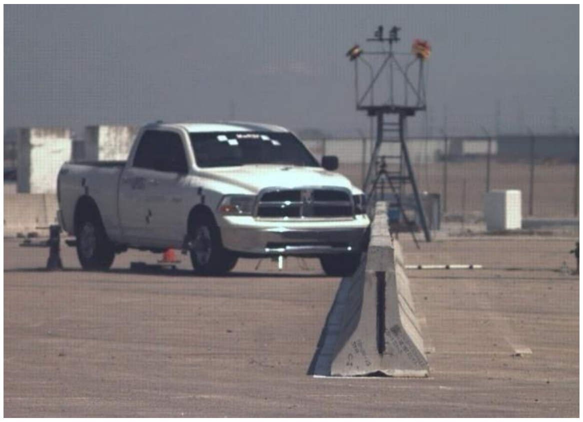
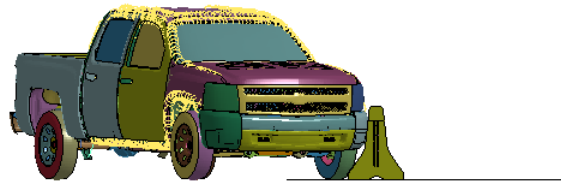
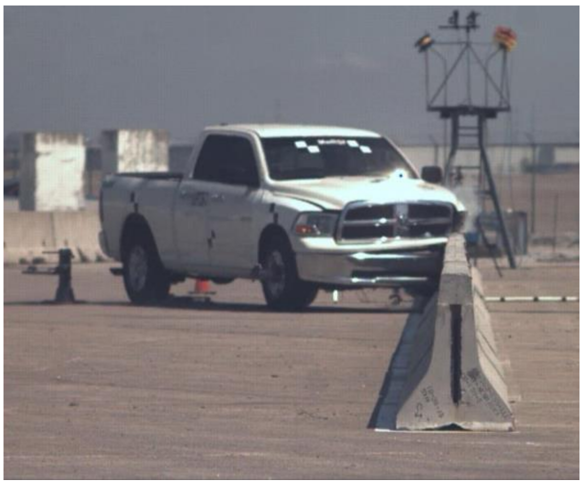
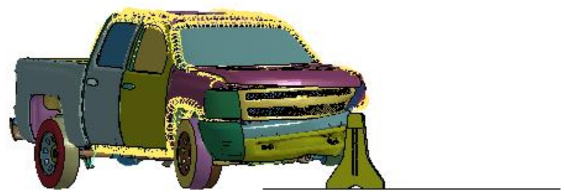


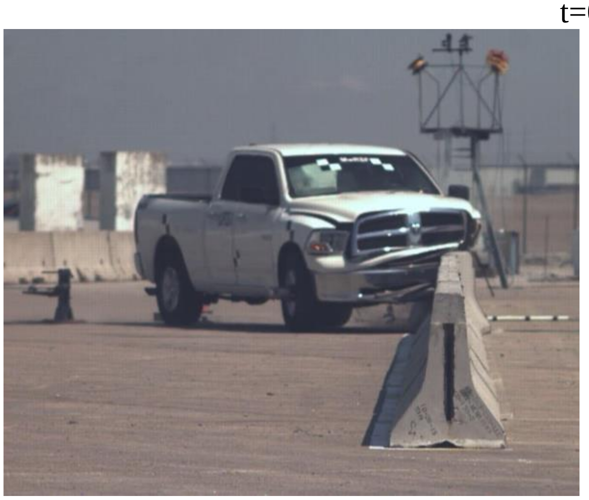
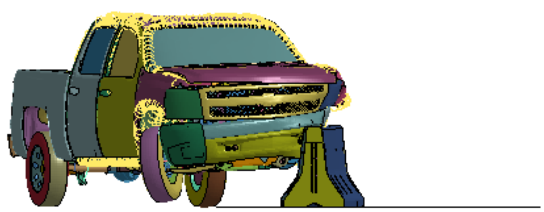
Figure 55. Overhead Sequential Views, Test No. NJPCB-3 and Simulation

t=0.000 s

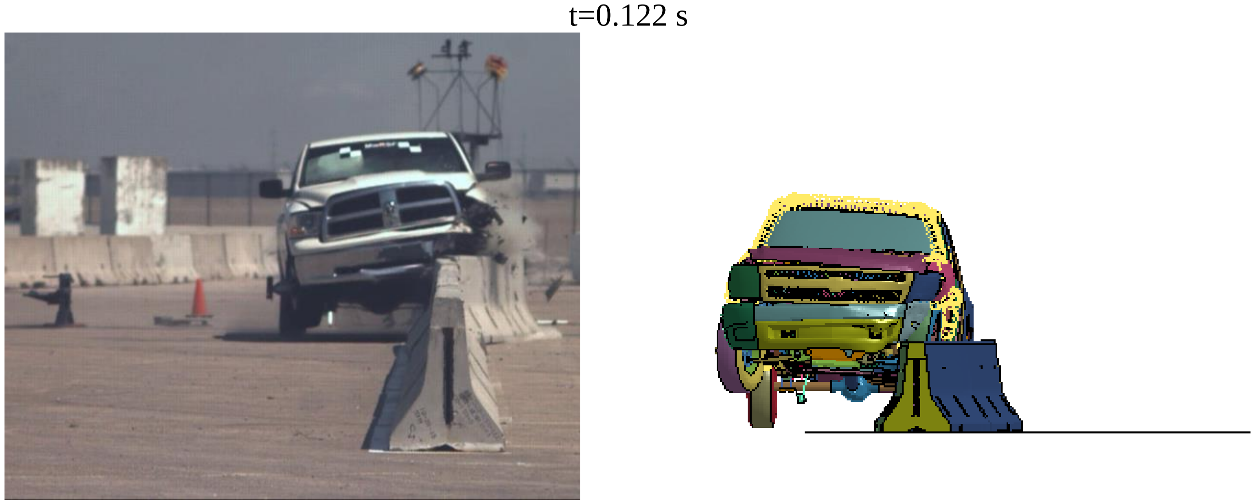
t=0.032 s

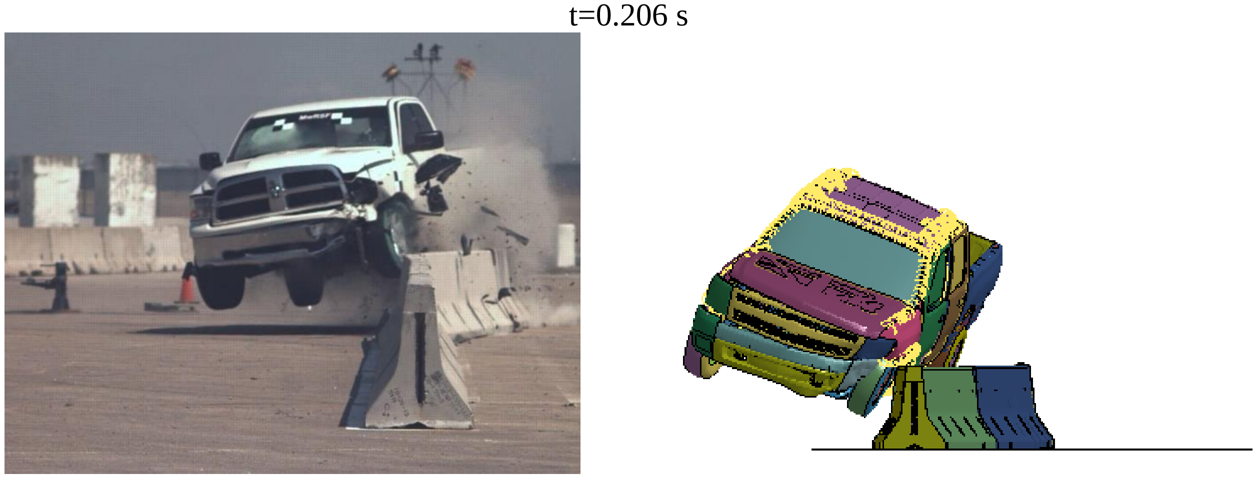
t=0.070 s

Figure 56. Downstream Sequential Views, Test No. NJPCB-3 and Simulation

t=0.122 s

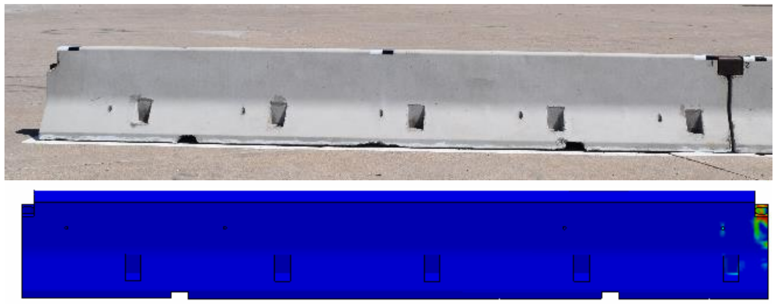


t=0.206 s

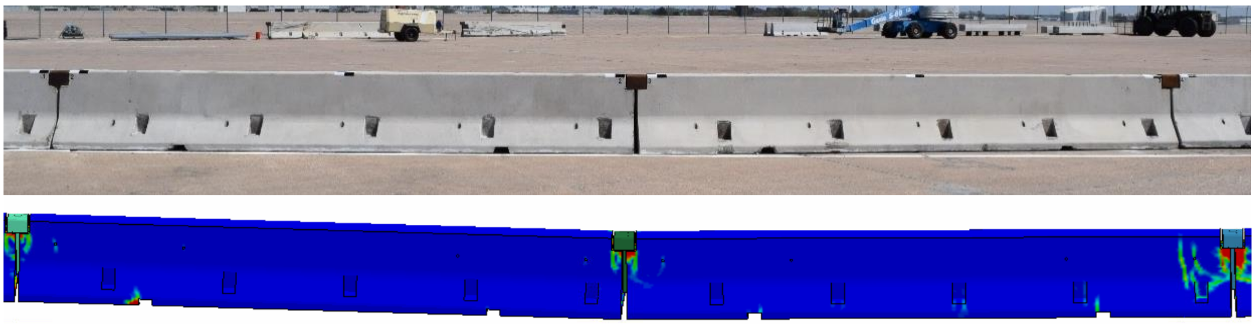


t=0.418 s

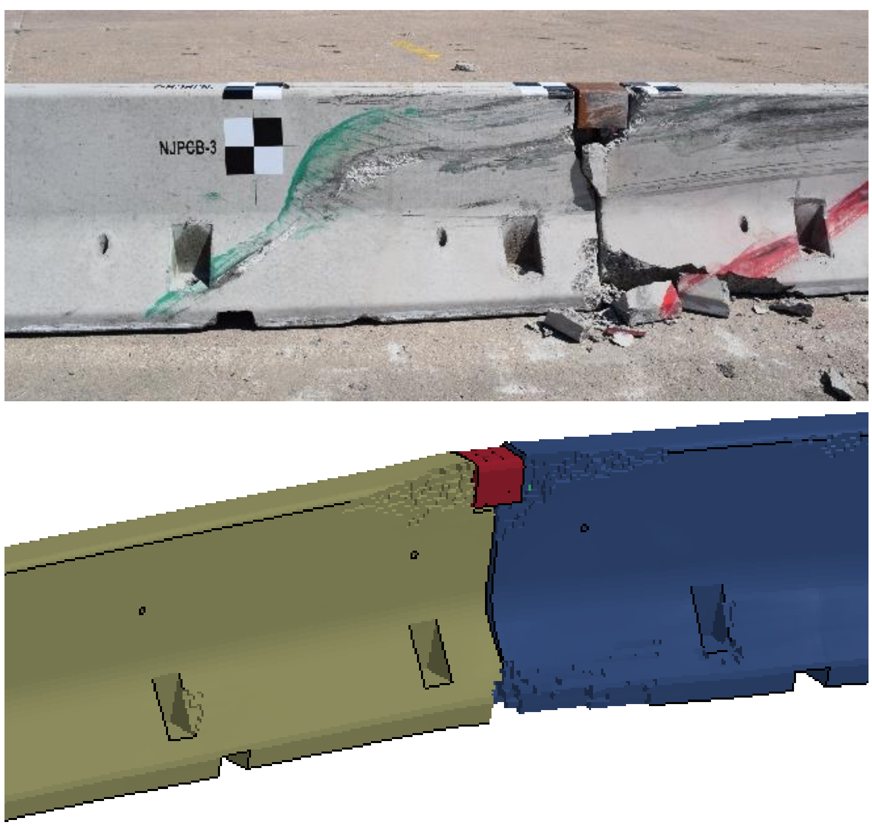
Figure 57. Downstream Sequential Views, Test No. NJPCB-3 and Simulation (cont'd)



(a) Damage on 1st barrier

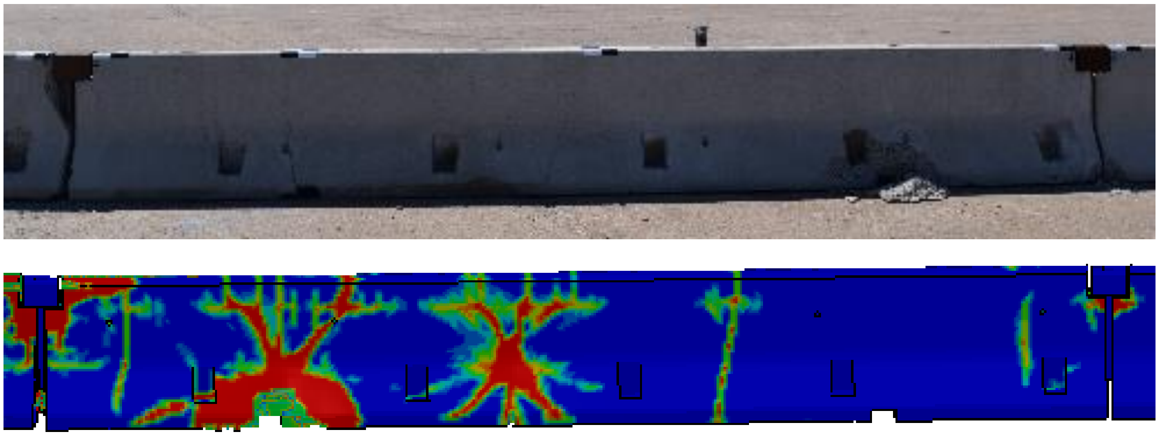


(b) Damage on 2nd and 3rd barriers

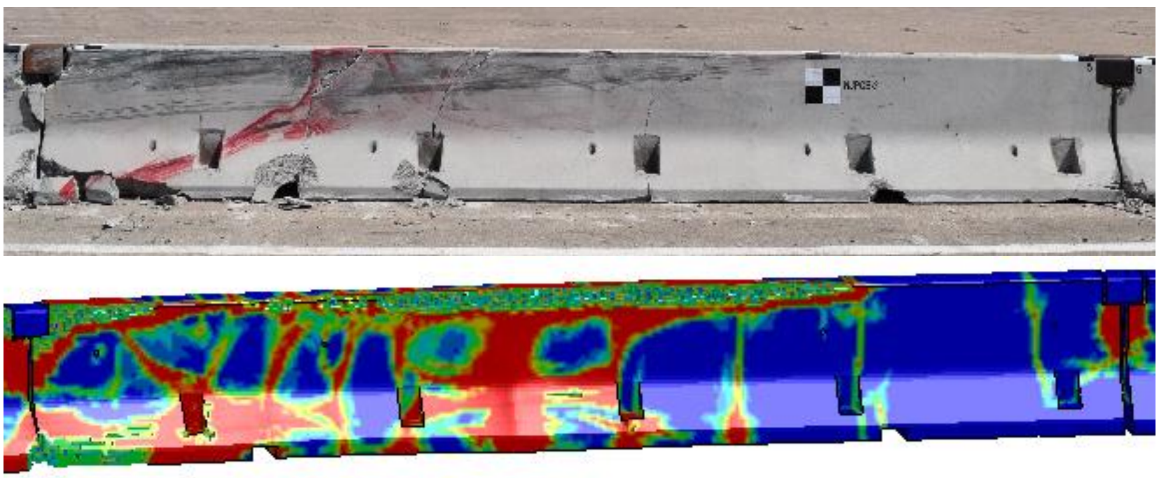


(c) Damage on 4th and 5th barriers

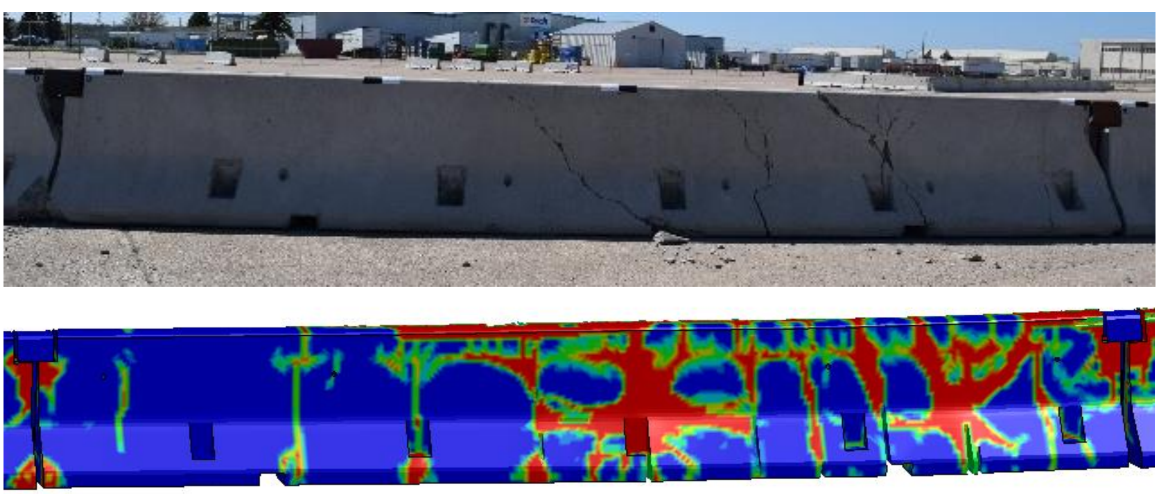
Figure 58. Barrier Segment Damage, Test No. NJPCB-3 and Simulation



(a) Cracks on the back face of 4th barrier

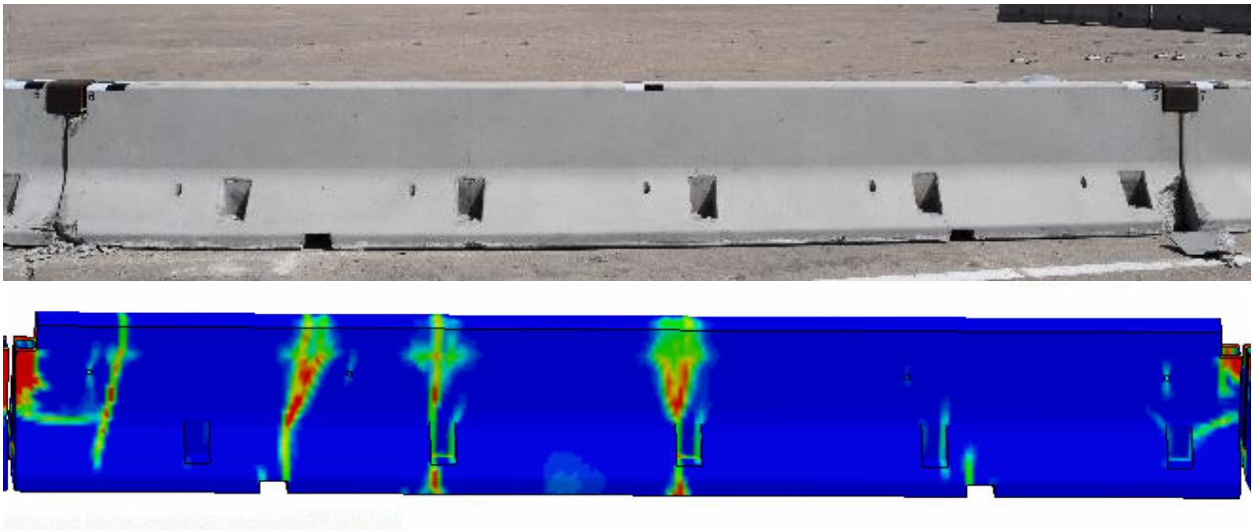


(b) Cracks on the front face of 5th barrier



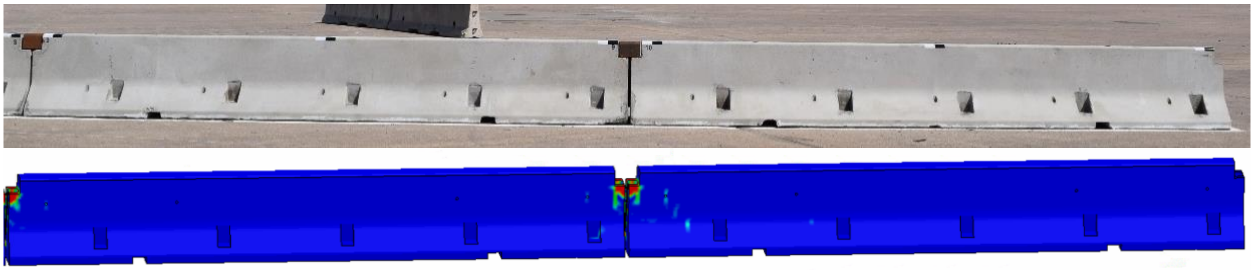
(c) Cracks on the back face of 5th barrier

Figure 59. Barrier Segment Damage, Test No. NJPCB-3 and Simulation (cont'd)



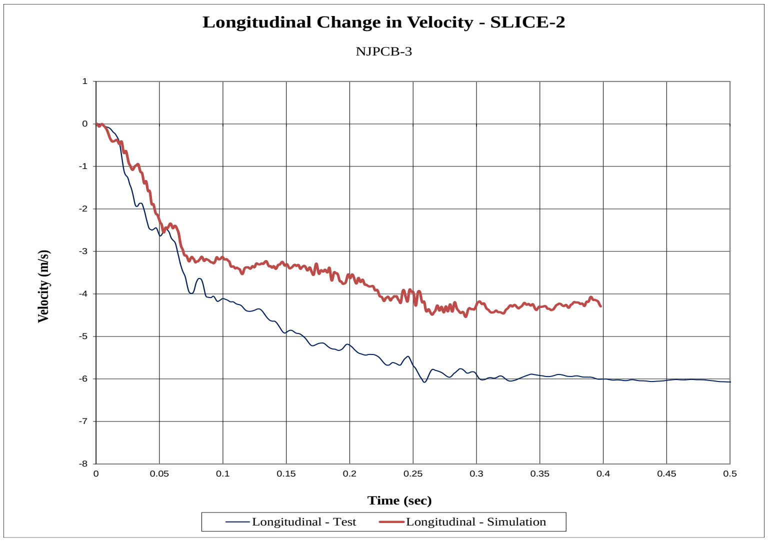
(a) Damage on 6th barrier

(b) Damage on 7th and 8th barrier

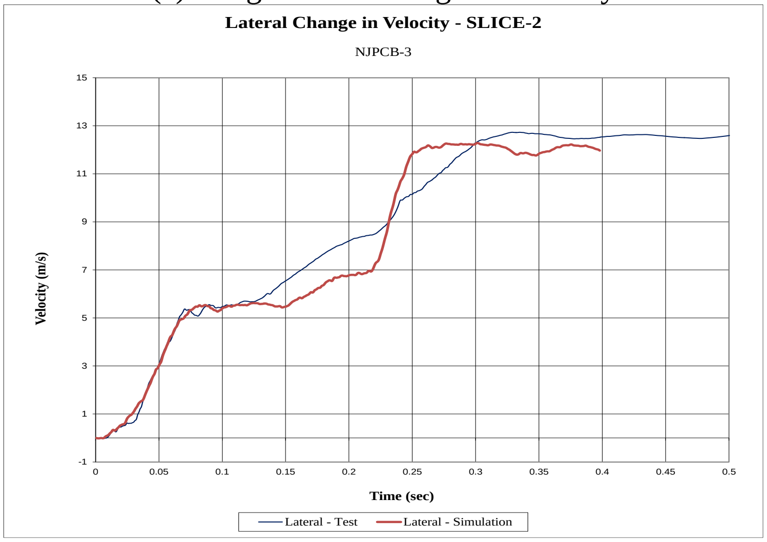


(c) Damage on 9th and 10th barrier

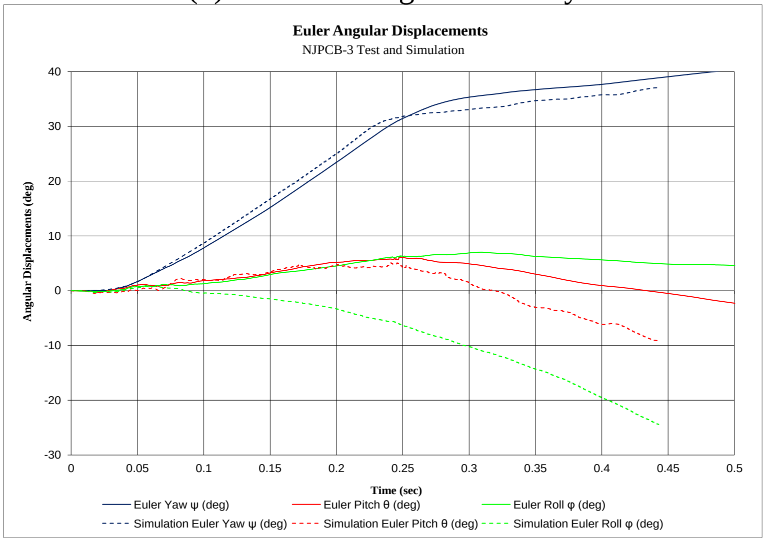
Figure 60. Barrier Segment Damage, Test No. NJPCB-3 and Simulation (cont'd)



(a) Longitudinal Change in Velocity



(b) Lateral Change in Velocity



(c)Euler Angular Displacements

Figure 61. Velocities and Euler Angular Displacements, Test No. NJPCB-3 and Simulation

Table 13. Dynamic Deflection, Test No. NJPCB-3 and Simulation

Evaluation Parameter	Test No. NJPCB-3	Simulation Model	Difference
Dynamic Deflection	38.1 in. (968 mm)	42.5 in. (1,080 mm)	+10%

9.2 Simulation of Crash Test No. NJPCB-5

The vehicle model used for the simulation was the Version 3, reduced-element, Chevrolet Silverado model developed at NCAC, and modified by MwRSF researchers for roadside safety applications [22]. In crash test no. NJPCB-5, a Dodge Ram pickup truck impacted the box-beam stiffened PCB system at a speed of 62.7 mph (100.8 km/h) and at an angle of 24.9 degrees. In the simulation of crash test no. NJPCB-5, the Chevrolet Silverado pickup truck model impacted the PCB model at a speed of 62.1 mph (100.0 km/h) and at an angle of 25 degrees. Initial vehicle impact was to occur $51^{3}/_{16}$ in. (1.3 m) upstream from the centerline of the joint between barrier nos. 4 and 5, as shown in Figure 62, which was modeled. The actual impact point in crash test no. NJPCB-5 was $49^{7}/_{16}$ in. (1.3 m) upstream from the centerline of the joint between barrier nos. 4 and 5.

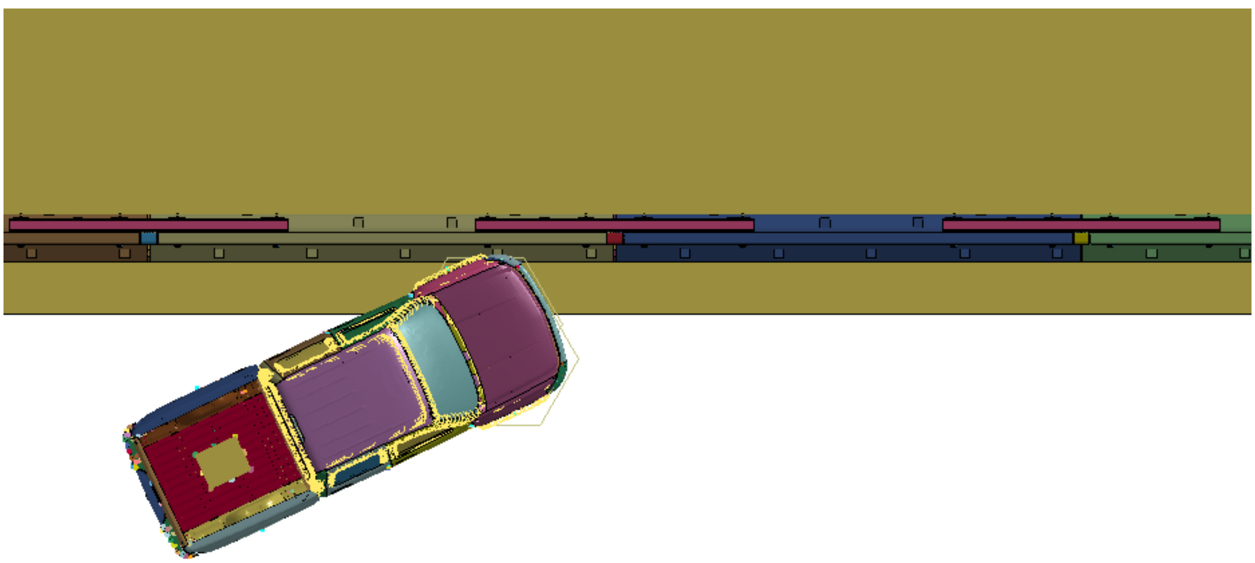


Figure 62. Model of Crash Test No. NJPCB-5 Impact Point

Graphical comparisons of the results from both the simulation and crash test no. NJPCB-5, as shown in Figures 63 through 67, showed that the behavior of the vehicle and the barrier in the simulation matched reasonably well with the full-scale crash test, and the vehicle was redirected by the PCB system. However, there was a noticeable difference in vehicle roll after 200 ms, as shown in Figures 64 and 68. These differences are believed to be due to inaccuracies in vehicle tire, suspension, and steering models, as well as friction, similar to the simulation of crash test no. NJPCB-3. However, these differences did not affect the redirection of the vehicle and are believed to minimally affect the loading of the barriers.

Comparison of barrier damage between the baseline model and crash test no. NJPCB-5, as shown in Figures 65 through 67, demonstrated that the barrier damage in the baseline model agreed well with full-scale test no. NJPCB-5. Cracking was discovered on barrier nos. 3, 4, 5, 6, 7, and 8.

The most cracks were found on the front, top, and back faces of barrier nos. 3, 4, and 5. Concrete spalling occurred on barrier nos. 3 through 8. Several pieces of concrete were disengaged from the front and back faces of barrier nos. 4 and 5. Grout between barrier nos. 4 and 5 disengaged.

The comparison of the dynamic deflection between crash test no. NJPCB-5 and the simulation is shown in Table 14. The dynamic deflection of the simulated barrier was determined to be 37.7 in. (957 mm) at the downstream end of the fourth barrier segment, as compared to the dynamic deflection of crash test no. NJPCB-5, which was measured to be 33.0 in. (838 mm) at the downstream end of the fourth barrier segment, as determined from high-speed digital video analysis. The simulated barrier displacement was 12 percent higher than the displacement observed in the full-scale crash test. Differences of up to 20 percent are usually considered acceptable when comparing displacements from simulations and full-scale crash tests.

Comparisons between longitudinal and lateral changes in velocity and Euler angular displacements of the simulation and crash test no. NJPBC-5 are shown in Figure 68. The differences in the longitudinal change in velocity and roll were greatest, which is partially due to the behavior of the impact-side front tire, frictions between the sheet metal, rubber, and barriers, and accentuated tail slap event, as described previously.

Based on the comparison, the simulation provided reasonable estimates of barrier deflection and damage under MASH TL-3 impact conditions. While some differences existed between the simulation and the crash test, the research team felt that accurate deflections and safety performance could still be estimated from the simulations. The differences were considered throughout the analysis, and the model limitations are further discussed in Section 9.3. The vehicle and barrier models were acceptable to evaluate the performance of the PCB system with shorter system lengths and to estimate barrier deflections.

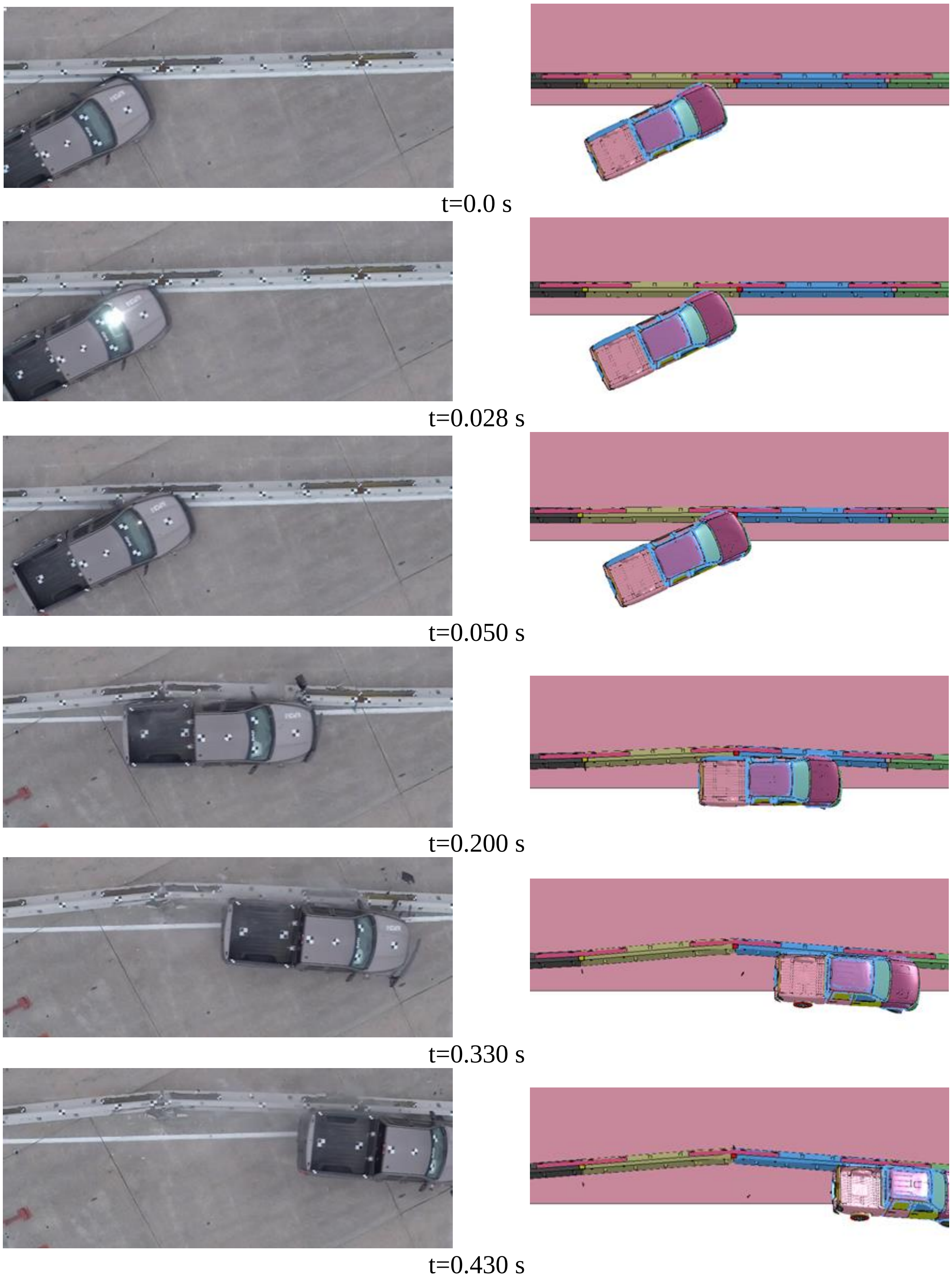


Figure 63. Overhead Sequential Views, Test No. NJPCB-5 and Simulation

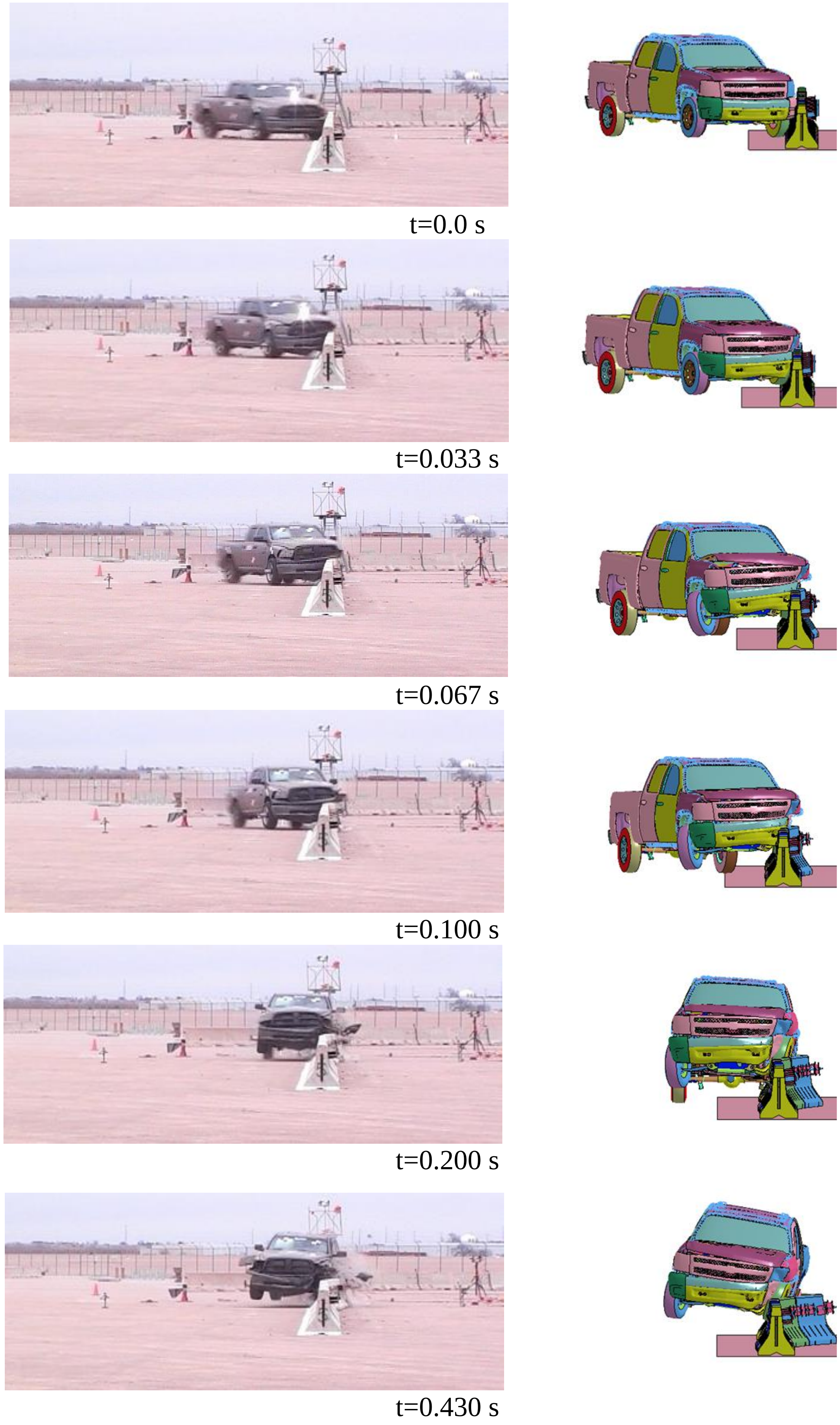
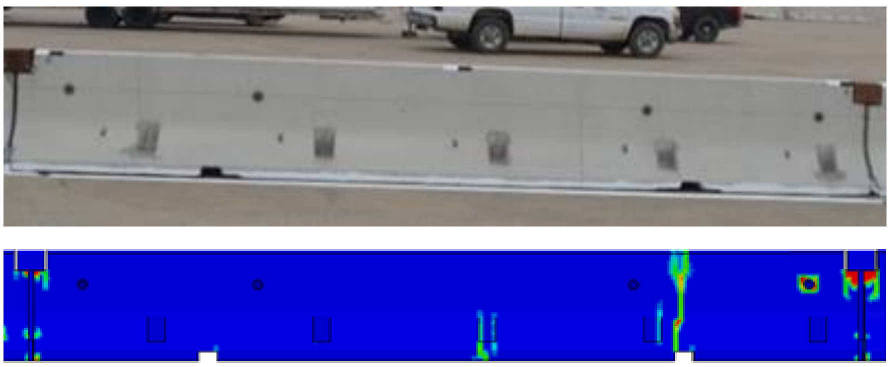
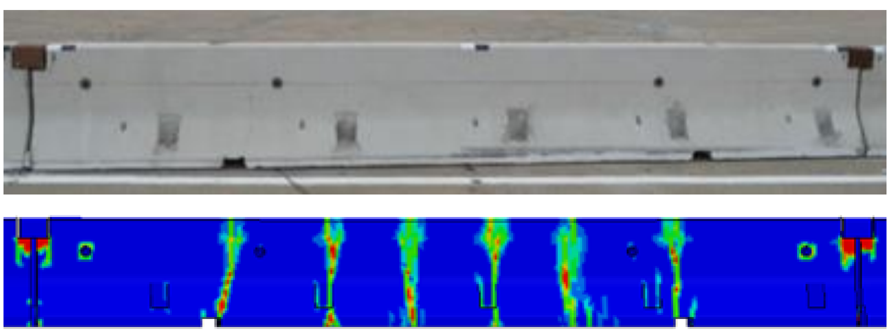


Figure 64. Downstream Sequential Views, Test No. NJPCB-5 and Simulation

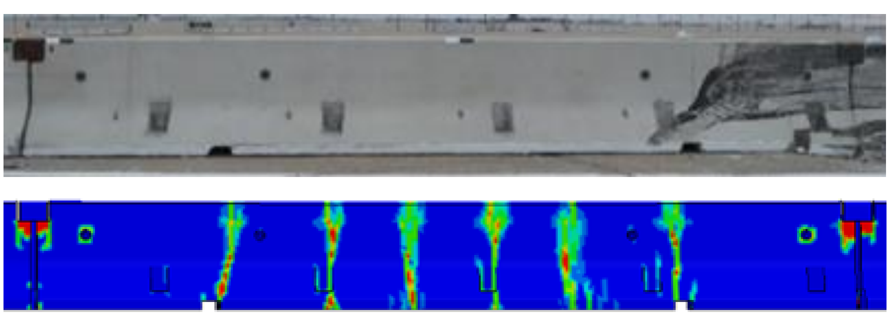
(a) 1st barrier



(b) 2nd barrier

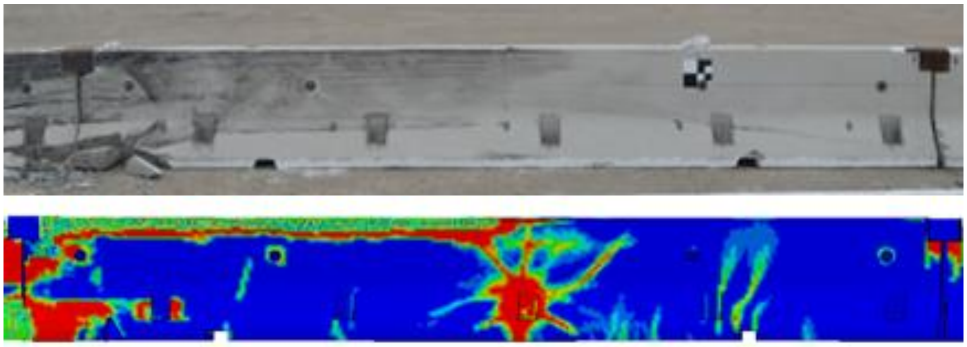


(c) 3rd barrier

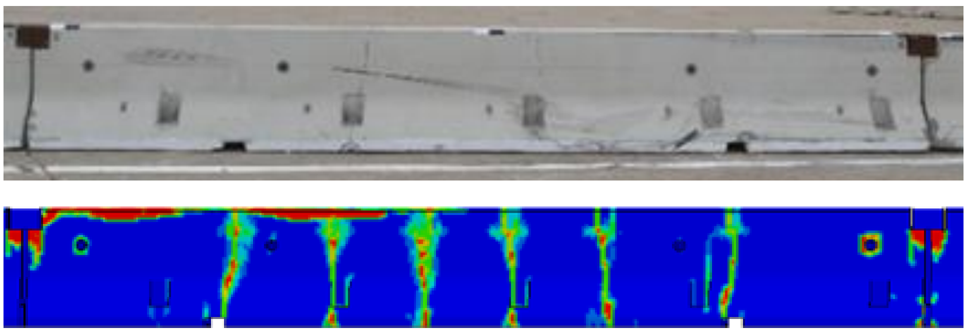


(d) 4th barrier

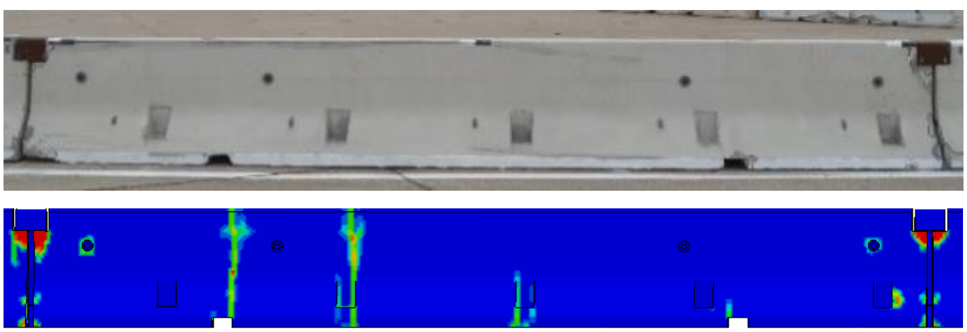
Figure 65. Barrier Segment Damage, Test No. NJPCB-5 and Simulation



(a) 5th barrier



(b) 6th barrier

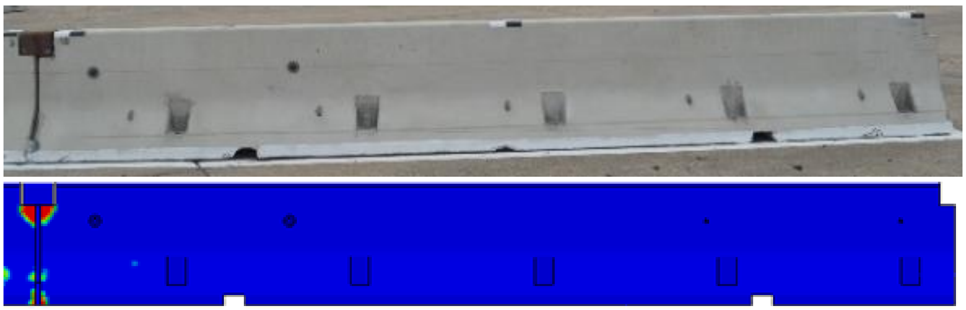


(c) 7th barrier

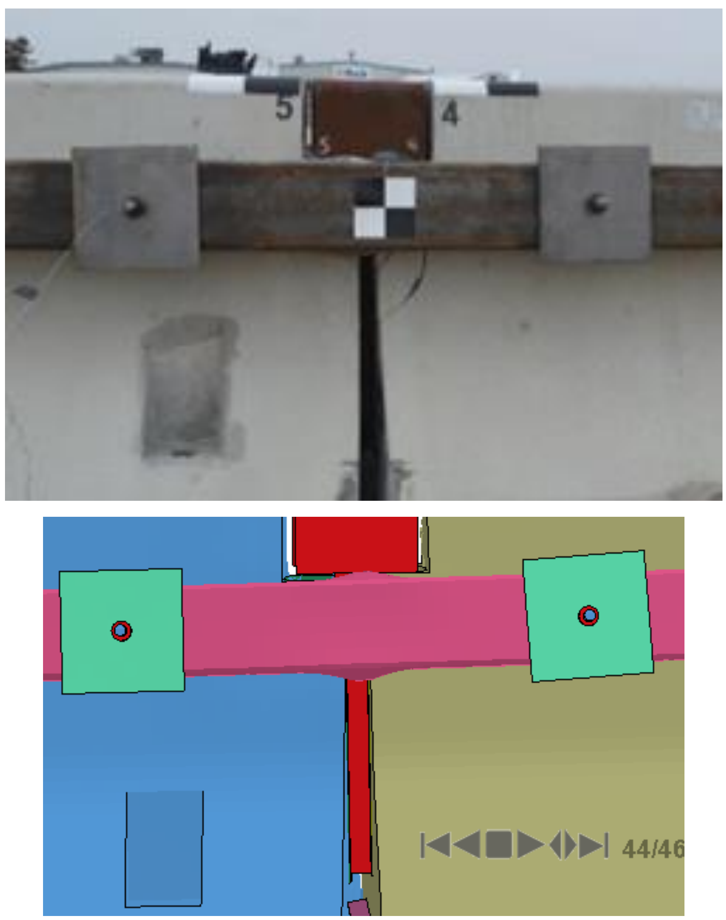
(d) 8th barrier

Figure 66. Barrier Segment Damage, Test No. NJPCB-5 and Simulation (cont'd)

(a) 9th barrier

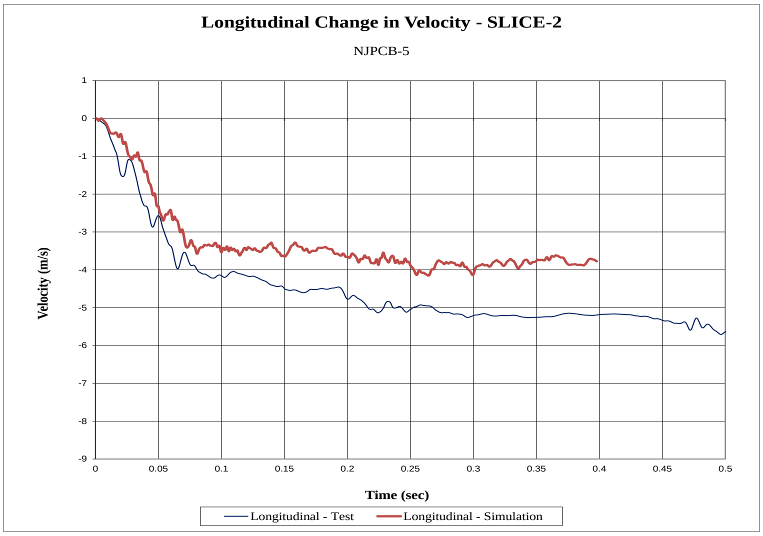


(b) 10th barrier

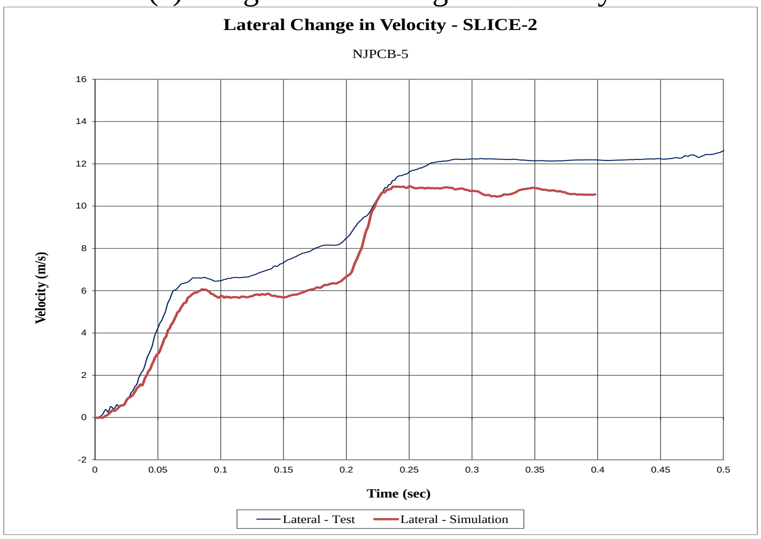


(c) Damage in tube between 4th and 5th barriers

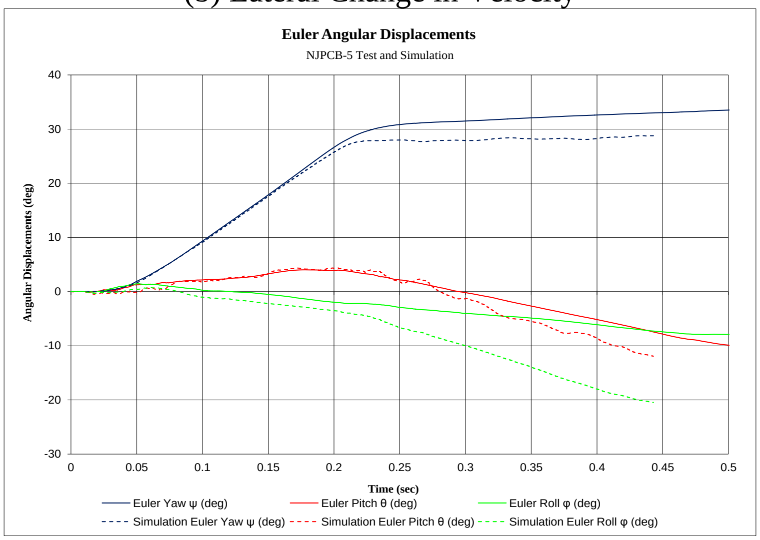
Figure 67. Barrier Segment Damage, Test No. NJPCB-5 and Simulation (cont'd)



(a) Longitudinal Change in Velocity



(b) Lateral Change in Velocity



(c) Euler Angular Displacements

Figure 68. Velocites and Euler Angular Displacements, Test No. NJPCB-5 and Simulation

Table 14. Dynamic Deflection, Test No. NJPCB-5 and Simulation

Evaluation Parameter	Test No. NJPCB-5	Simulation Model	Difference
Dynamic Deflection	33.0 in. (838 mm)	37.7 in. (957 mm)	+12%

9.3 Model Limitations

The primary objective of the simulation effort was to estimate the safety performance and barrier deflections of reduced-length barrier systems. All computer simulations have limitations. For this particular simulation effort, the representative pickup truck vehicle model was developed by NCAC and modified by MwRSF researchers. The selected vehicle model does not have failure in the suspension or steering components, and the tires are much stiffer than actual vehicle tires. Further, refinement of these components would require a significant research effort, which was outside the scope of this project. As shown in the simulation and test sequential image comparison for test nos. NJPCB-3 and NJPCB-5 (Figures 56, 57, and 64), the right-front tire in the simulation turns toward the right (passenger side) very shortly after impact, which does not happen in the actual tests. This behavior is believed to be due to the tire's stiffness and lack of suspension failure and steering in the vehicle model. This behavior likely also leads to differences in the vehicle motion (roll and pitch) later in the impact event. Similar truck behavior has been noted in other similar simulations, and the differences in vehicle motion and trajectory were considered throughout the simulation effort. Also, the rear axle of the Chevrolet Silverado model is stiffer than observed for actual pickup truck axle behavior. Thus, the tail slap event in simulations always produces a greater impact force due to the way it is modelled, and also shows greater variations in accelerations, velocities, and Euler angular displacements after tail slap occurs.

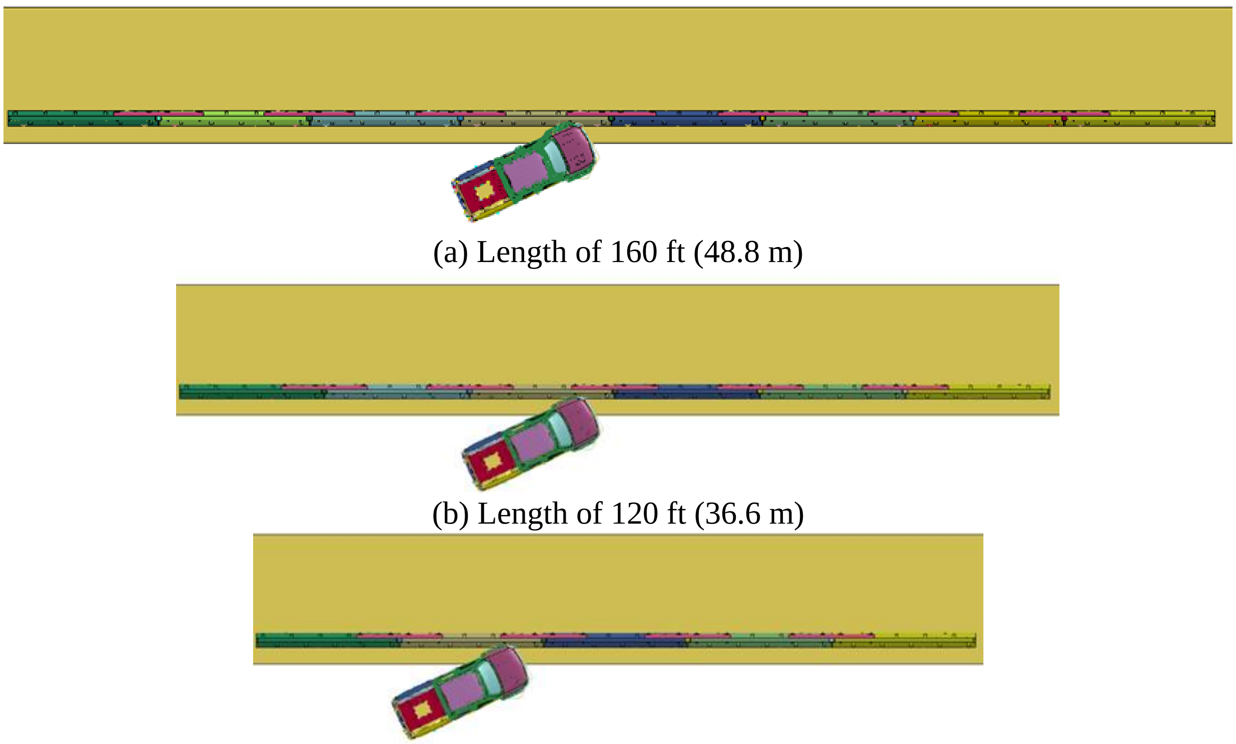
Even though the overall simulated truck motion and trajectory differs from those behaviors observed in the crash tests, the barrier deflections and damage that occurred in the simulations were very close to what occurred in actual tests, which led researchers to believe that models were adequate for evaluating barrier deflections. The simulated barrier deflections were slightly over-predicted, which will be accounted for and will produce conservative results when looking at the reduced-length barrier systems. The safety performance measures from the simulation effort were more subjective due to the aforementioned differences in vehicle motion.

9.4 Reduced-Length Analysis

The baseline simulation of the NJDOT box-beam stiffened PCB system, corresponding to crash test no. NJPCB-5, was modified with reduced system lengths to estimate safety performance and maximum barrier deflections. The reduced-length barrier models had total system lengths of 160 ft (48.8 m), 120 ft (36.6 m), and 100 ft (30.5 m). The end barrier segments were pinned in each system.

All of the simulations on reduced-length systems were conducted with the Chevrolet Silverado model impacting upstream from the impact point used in the baseline model. An evaluation of numerous impact points was outside the scope of this study. However, the impact points for the reduced-length systems were selected to maintain consistency with the baseline model and were anticipated to produce the maximum barrier deflection. The impact points for the pickup trucks in the simulations were 4 ft – $3^{3}/_{16}$ in. (1.3 m) upstream from the centerline of the joint between barrier nos. 4 and 5, barrier nos. 3 and 4, and barrier nos. 2 and 3, respectively, for the 160-ft (48.8-m), 120-ft (36.6-m), and 100-ft (30.5-m) long systems, as shown in Figure 69. All the models were simulated with the Chevrolet Silverado pickup truck model impacting the PCB system at a speed of 62.1 mph (100.0 km/h) and at an angle of 25 degrees.

The barrier models with shorter installation lengths appeared to smoothly redirect the vehicle with moderate damage to both the barrier and the vehicle, as shown in Figures 70 through 78.



(a) Length of 160 ft (48.8 m)

(b) Length of 120 ft (36.6 m)

(c) Length of 100 ft (30.5 m)

Figure 69. Reduced-Length PCB Systems - Impact Points

Barrier damage of shorter installation lengths was moderate, as shown in Figures 76 through 78. In the 160-ft (48.8-m) model, concrete spalling occurred on the front, back, and top face of barrier nos. 4 and 5. Cracking was found on barrier nos. 3, 4, 5 and 6. Several pieces of concrete disengaged from barrier nos. 4 and 5. In the 120-ft (36.6-m) model, cracking occurred on barrier nos. 1, 2, 3, 4, and 5. Concrete spalling occurred on the faces of barrier nos. 3 and 4. Some pieces of concrete disengaged from barrier nos. 3 and 4. In the 100-ft (30.5-m) model, cracking occurred on the faces of barrier nos. 1, 2, 3, 4, 5, and 6. Concrete spalling occurred on the front and back faces of barrier nos. 2 and 3. Some pieces of concrete disengaged from the barrier nos. 2 and 3.

A reduction in the total system length was anticipated to provide decreased dynamic deflection during impact with the barrier system, as the ends of each system were pinned. Maximum dynamic deflections of 37.4 in. (950 mm), 35.8 in. (909 mm), and 28.7 in. (729 mm) were measured for the 160-ft (48.8-m), 120-ft (36.6-m), and 100-ft (30.5-m) long barrier models, respectively, as shown in Table 15. The maximum dynamic deflections occurred at the upstream end of barrier nos. 5, 4, and 3 for the 160-ft (48.8-m), 120-ft (36.6-m), and 100-ft (30.5-m) long barrier models, respectively. As mentioned previously, the baseline simulation deflection was 12 percent greater than the deflection observed in crash test no. NJPCB-5. Thus, the results from the reduced-deflection analysis are likely higher than what may occur in physical crash tests. To account for the model deflection discrepancies, the simulated barrier deflections were reduced by 12 percent so that crash test no. NJPCB-5 and its corresponding simulation had the same dynamic deflection (33.0 in. (838 mm)), as shown in Table 16. Additionally, the simulated deflections for the reduced-length PCB systems (Table 15) were reduced by 12 percent to account for the model deflection discrepancies and are shown in Table 16. The adjusted dynamic deflections shown in Table 16 may correlate better with physical crash tests.

For shorter system lengths, the end constraints will have a greater effect on the system behavior. With the 200-ft (61.0-m) long system, five barriers displaced laterally and the end barriers displaced minimally longitudinally, which indicated the pinned end did not significantly control system behavior. With the 160-ft (48.8-m), 120-ft (36.6-m), and 100-ft (30.5-m) system lengths, five, four, and three barriers displaced laterally, respectively. Especially for the 120-ft (36.6-m) and 100-ft (30.5-m) long systems, all unrestrained barriers displaced laterally and the end pinned barriers could not displace. Thus, the end constraints significantly affected deflections. It should be noted that the capacity of the pins were not evaluated during this simulation effort, as it was outside the scope of the original project. The end barriers had constraints to simulate pinned segments. However, especially at the short barrier length, the end barriers would experience higher loads, and it is unknown if the pins would permanently deform or fracture. If significant deformation or fracture of the pins occurred, the barrier deflections would likely increase from those found in the simulations.

The reduced-length systems, especially those at 100 ft (30.5 m) and 120 ft (36.6 m) long, experienced much more concrete damage than observed in the 200-ft (61.0-m) long system. The spalling of the concrete in the model may not be entirely accurate. However, if significant concrete fracture and spalling does occur to the concrete, the impact side tires may interact with the spalled concrete barrier differently than when the barriers remain intact. As mentioned previously, the behavior of the tire and tire-to-barrier contact is difficult to accurately predict without verification through full-scale crash testing. Thus, the behavior of the vehicle should be used cautiously.

Overall, the reduced-length systems appeared to have acceptable safety performance according to the MASH test designation no. 3-11 safety performance criteria. However, occupant impact velocities and occupant ridedown accelerations were not calculated, and the vehicle model tends to over-predict lateral occupant ridedown acceleration due to the overly stiff tail slap event. Additionally, due to the model limitations noted previously, all possible failure modes that could occur are not being modeled. Occupant compartment damage due to the impact-side tire pushing up into the floorboard is likely inaccurate due to the lack of steering and tire and suspension failure mentioned previously. Wheel climb on the barrier, which could lead to override or vehicle rollover, may also not be accurate if tire or suspension failure would otherwise occur, which is unknown without conducting further physical testing. The main objective of the simulation was to estimate barrier deflections, and the deflections found should be conservative and reasonably accurate. The overall safety performance of the barrier system, as determined from computer simulation, should be used cautiously.

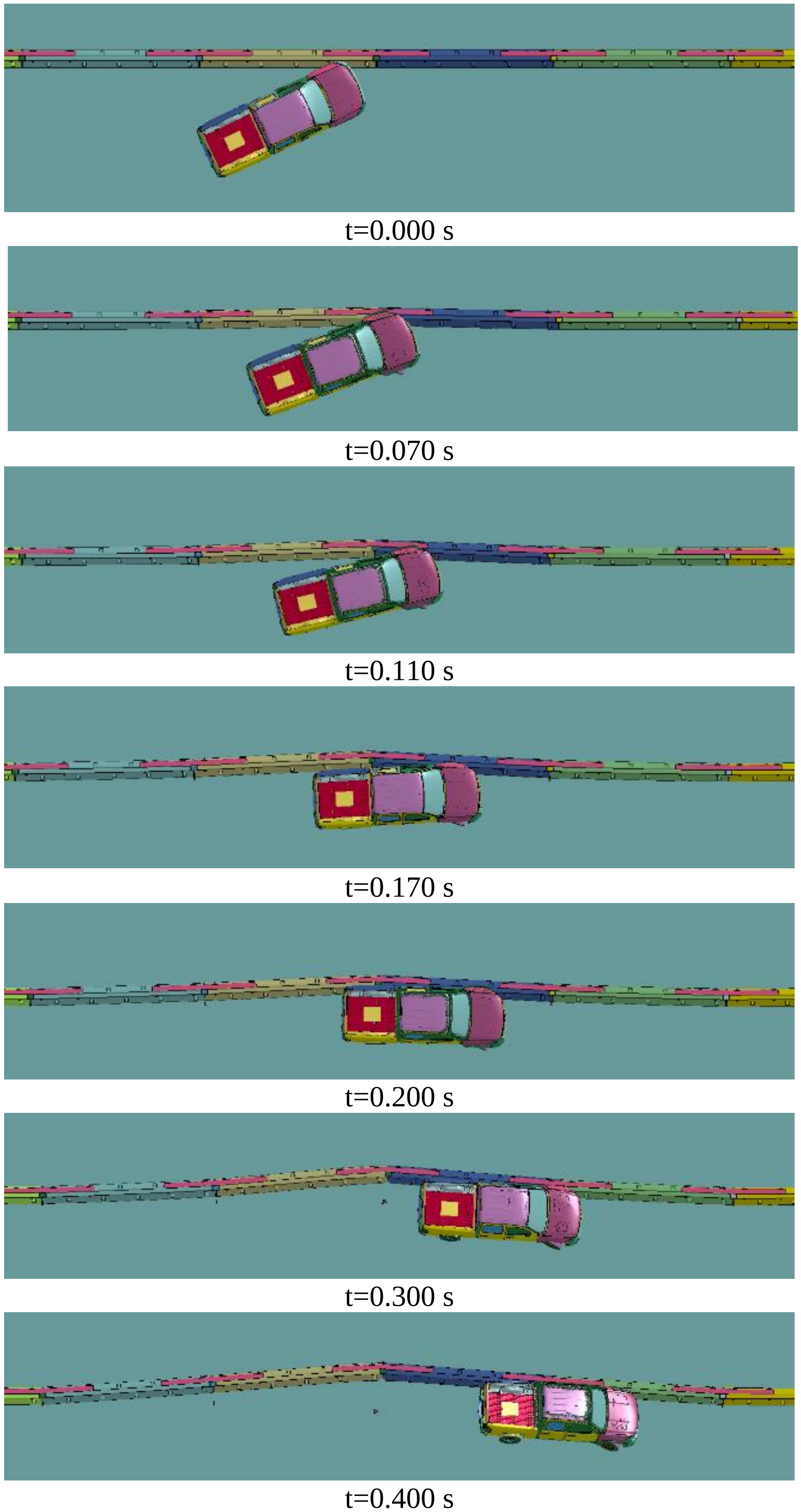


Figure 70. 160-ft Length, Reduced-Deflection PCB Simulation, Overhead Sequential Views

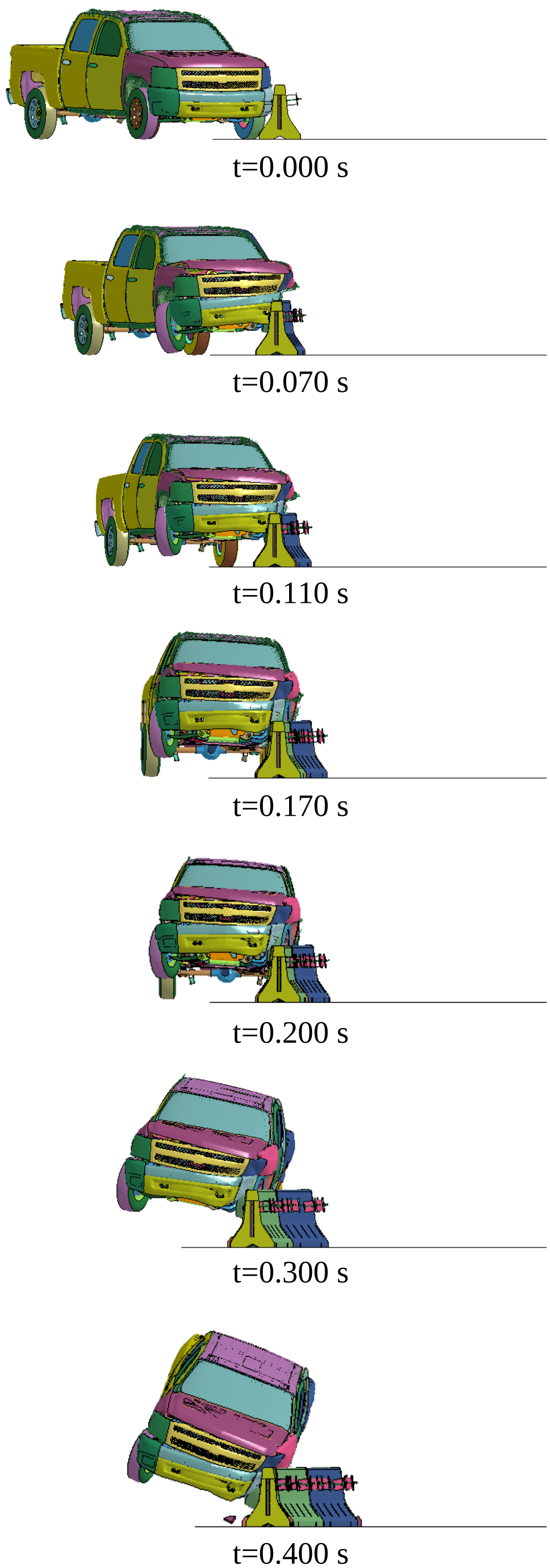
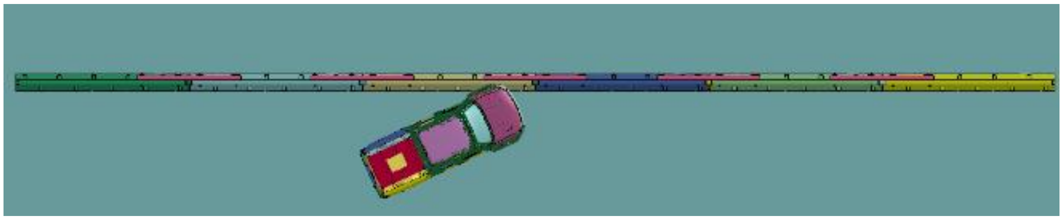
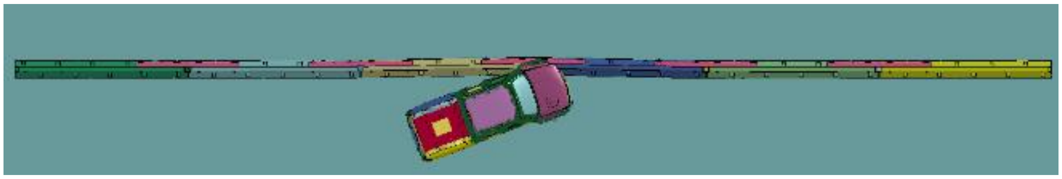


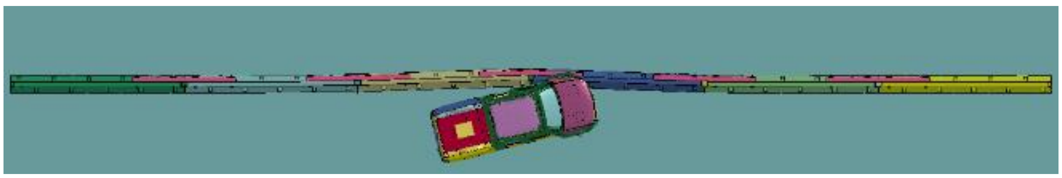
Figure 71. 160-ft Length, Reduced-Deflection PCB Simulation, Downstream Sequential Views



t=0.000 s

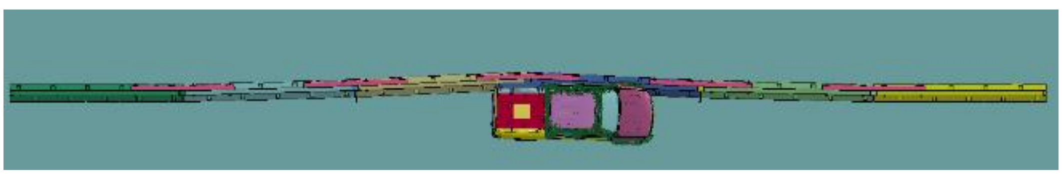


t=0.070 s

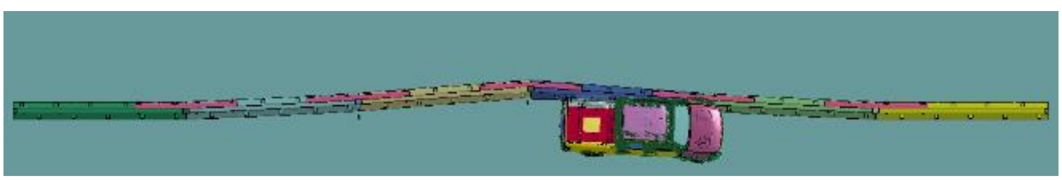


t=0.110 s

t=0.170 s



t=0.200 s



t=0.300 s

t=0.400 s

Figure 72. 120-ft Length, Reduced-Deflection PCB Simulation, Overhead Sequential Views

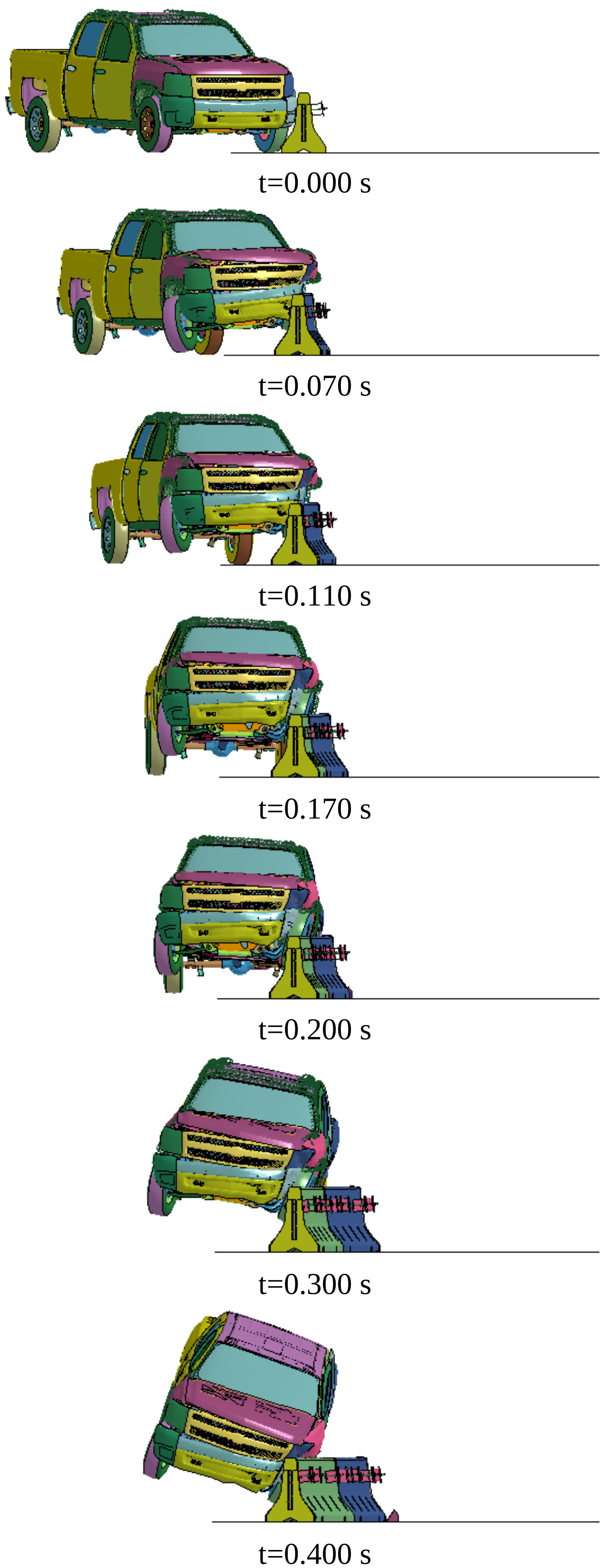
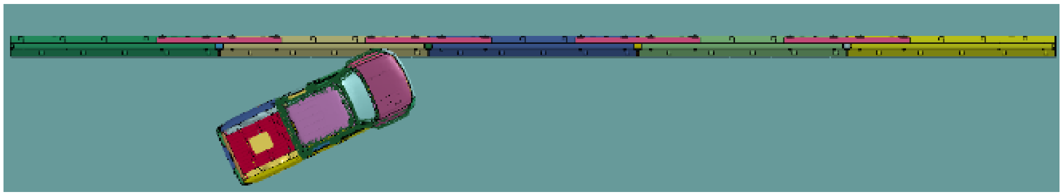
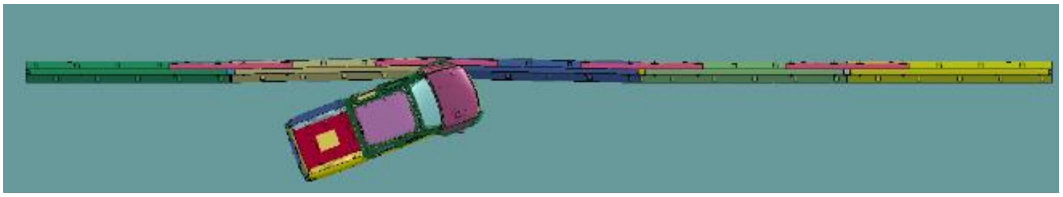


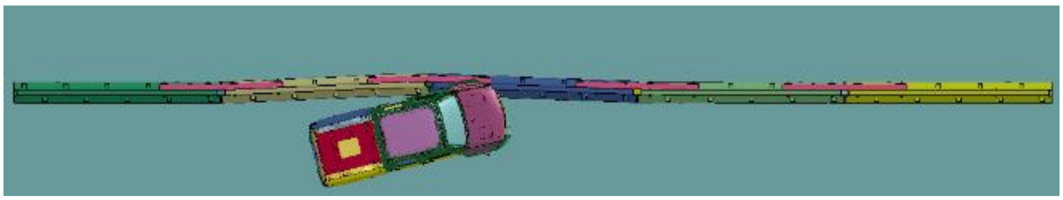
Figure 73. 120-ft Length, Reduced-Deflection PCB Simulation, Downstream Sequential Views



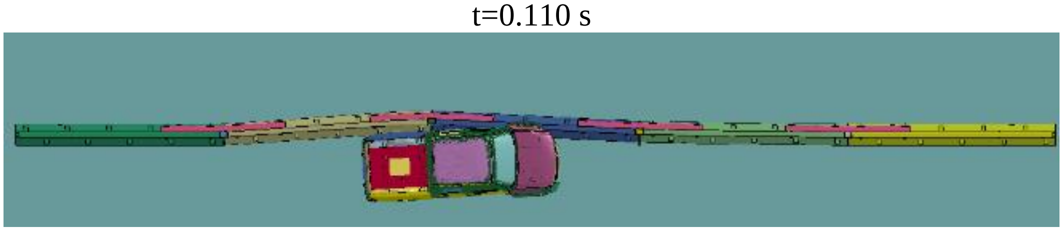
t=0.000 s



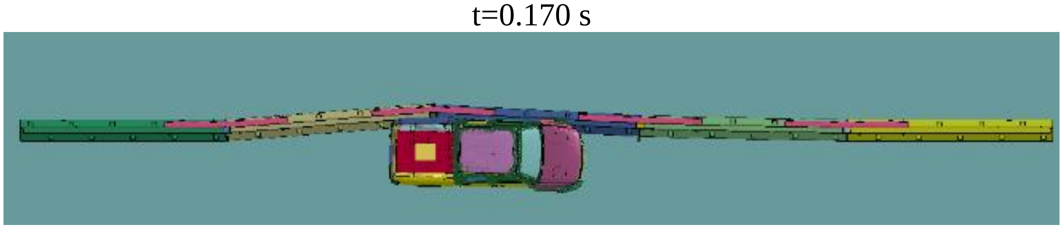
t=0.070 s



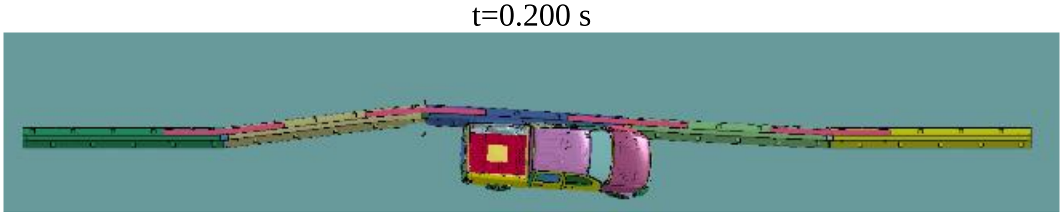
t=0.110 s



t=0.170 s



t=0.200 s



t=0.300 s

t=0.400 s

Figure 74. 100-ft Length, Reduced-Deflection PCB Simulation, Overhead Sequential Views

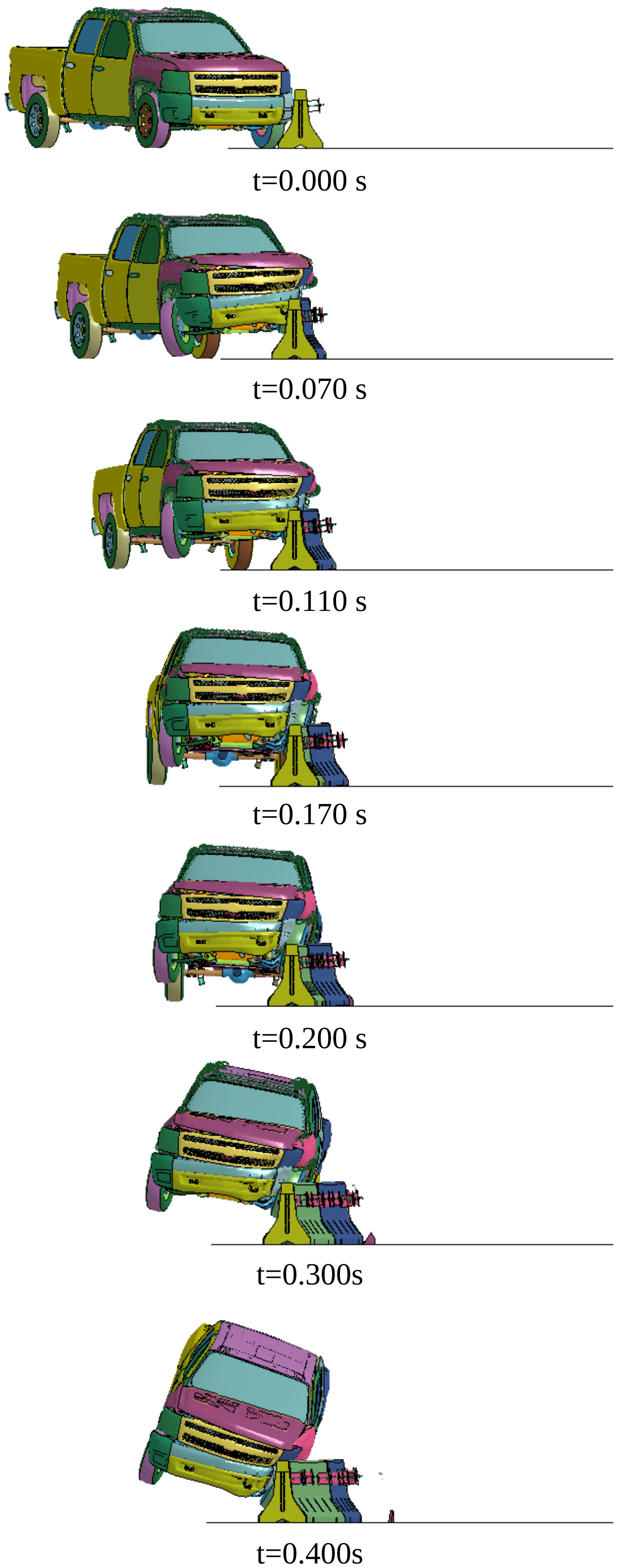
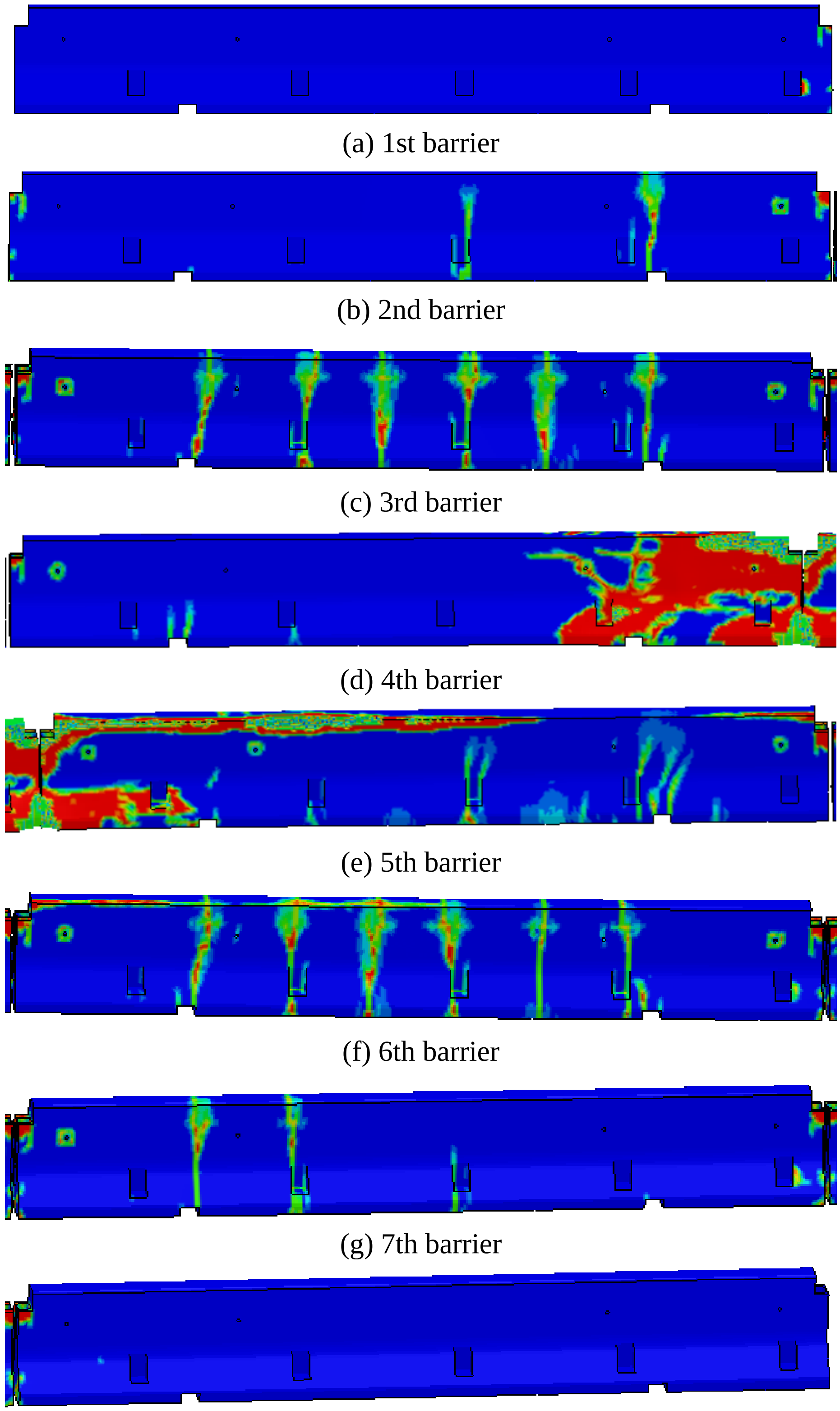


Figure 75. 100-ft Length, Reduced-Deflection PCB Simulation, Downstream Sequential Views



(a) 1st barrier

(b) 2nd barrier

(c) 3rd barrier

(d) 4th barrier

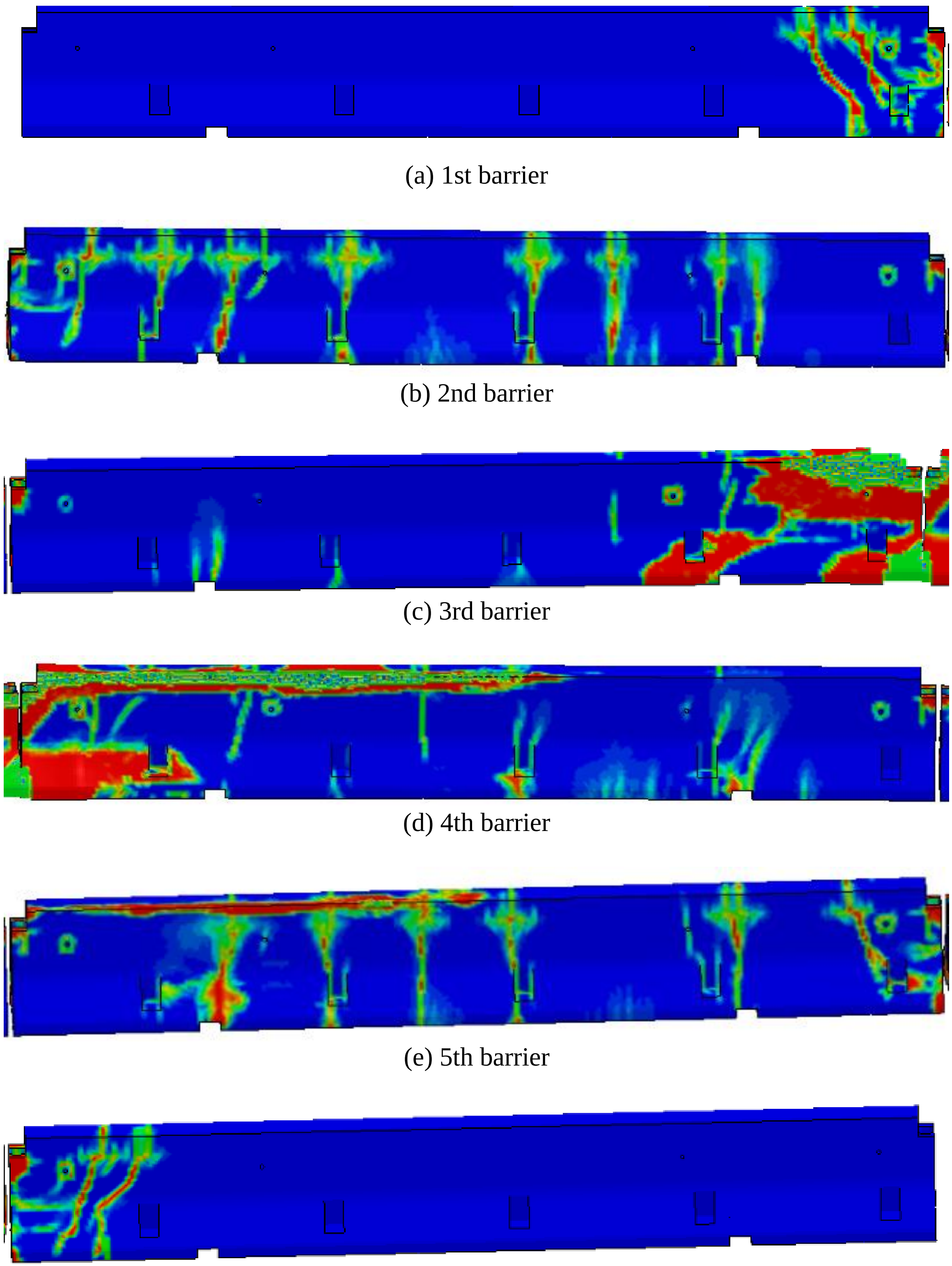
(e) 5th barrier

(f) 6th barrier

(g) 7th barrier

(h) 8th barrier

Figure 76. 160-ft Length, Reduced-Deflection PCB Simulation, Barrier Damage



(a) 1st barrier

(b) 2nd barrier

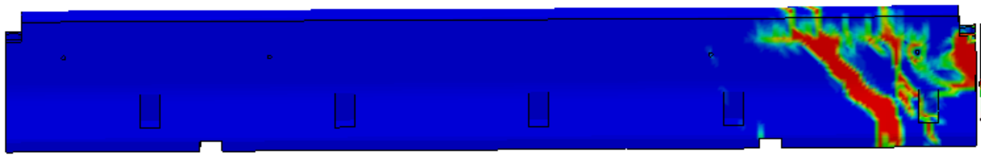
(c) 3rd barrier

(d) 4th barrier

(e) 5th barrier

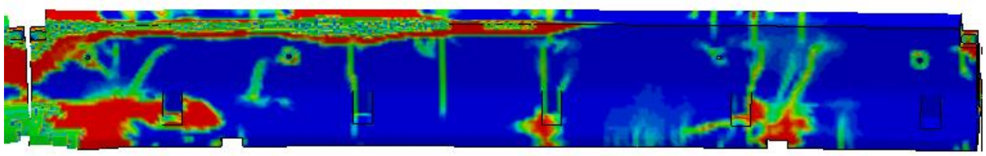
(f) 6th barrier

Figure 77. 120-ft Length, Reduced-Deflection PCB Simulation, Barrier Damage

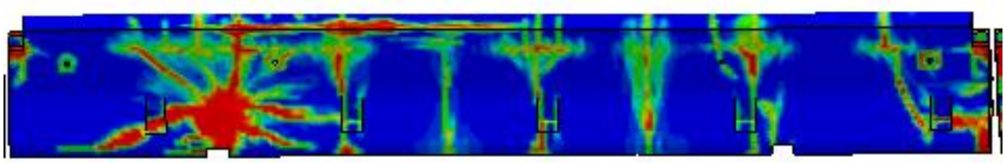


(a) 1st barrier

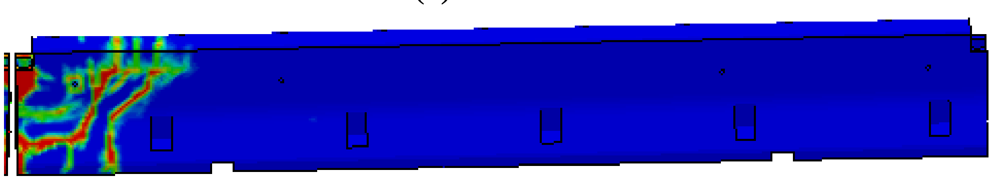
(b) 2nd barrier



(c) 3rd barrier



(d) 4th barrier



(e) 5th barrier

Figure 78. 100-ft Length, Reduced-Deflection PCB Simulation, Barrier Damage

Table 15. Dynamic Deflection of Reduced-Length Barrier Systems, Actual Simulated Results

Evaluation Parameter	Dynamic Deflection By System Length			
	200 ft (61.0 m)	160 ft (48.8 m)	120 ft (36.6 m)	100 ft (30.5 m)
Dynamic Deflection	37.5 in. (957 mm)	37.6 in. (954 mm)	35.8 in. (910 mm)	28.7 in. (730 mm)

Table 16. Dynamic Deflection of Reduced-Length Barrier Systems, Adjusted Simulation Results

Evaluation Parameter	Adjusted Dynamic Deflection By System Length (12% Reduction)			
	200 ft (61.0 m)	160 ft (48.8 m)	120 ft (36.6 m)	100 ft (30.5 m)
Dynamic Deflection	33.0 in. (838 mm)	32.9 in. (836 mm)	31.5 in. (800 mm)	25.3 in. (642 mm)

10 MASH IMPLEMENTATION

The objective of this research was to evaluate the safety performance of NJDOT's PCB, Type 4 (Alternative B) system with a box-beam stiffened, free-standing configuration and grouted toes, corresponding to connection type B in the 2015 NJDOT *Roadway Design Manual*. The NJDOT barriers consisted of NJDOT PCBs joined with a connection key. Barrier nos. 1 and 10 were anchored to the concrete roadway surface through the nine pin anchor recesses with 1-in. (25-mm) diameter by 15-in. (381-mm) long, ASTM A36 steel pins. The nine joints between barrier nos. 1 through 10 were stiffened with a 12-ft (3.7-m) long, 6-in. × 6-in. × $^3/_{16}$-in. (152-mm × 152-mm × 5-mm) ASTM A500 Grade C box beam rail. The barrier segments were pulled in a direction parallel to their longitudinal axes, and slack was removed from all joints prior to installation of the steel anchor pins. A wedge of grout was placed at the toe of each joint on both the traffic side and back side of the system.

According to TL-3 evaluation criteria in MASH 2016, two tests are required for evaluation of longitudinal barrier systems: (1) test designation no. 3-10 – an 1100C small car and (2) test designation no. 3-11 – a 2270P pickup truck. However, only the 2270P crash test was deemed necessary as other prior small car tests were used to support a decision to deem the 1100C crash test not critical.

In test no. 7069-3, a rigid, F-shape bridge rail was successfully impacted by a small car weighing 1,800 lb (816 kg) at 60.1 mph (96.7 km/h) and 21.4 degrees according to the American Association of State Highway and Transportation Officials (AASHTO) *Guide Specifications for Bridge Railings* [5-6]. In the same manner, test nos. CMB-5 through CMB-10, CMB-13, and 4798-1 showed that rigid, New Jersey, concrete safety shape barriers struck by small cars have been shown to meet safety performance standards [7-9]. In addition, in test no. 2214NJ-1, a rigid, New Jersey, ½-section, concrete safety shape barrier was impacted by a passenger car weighing 2,579 lb (1,170 kg) at 60.8 mph (97.8 km/h) and 26.1 degrees according to the TL-3 standards set forth in MASH 2009 [9]. Furthermore, temporary, New Jersey safety shape, concrete median barriers have experienced only slight barrier deflections when impacted by small cars and behave similarly to rigid concrete barriers as seen in test no. 47 [10]. Therefore, the 1100C passenger car test was deemed not critical for testing and evaluating this PCB system. It should be noted that any tests within the evaluation matrix deemed not critical may eventually need to be evaluated based on additional knowledge gained over time or additional FHWA eligibility letter requirements.

During test no. NJPCB-5, a 5,001-lb (2,268 kg) pickup truck with a simulated occupant seated in the left-front seat impacted the box-beam stiffened NJDOT PCB system, corresponding to connection type B in the 2015 NJDOT *Roadway Design Manual*, at a speed of 62.7 mph (100.8 km/h) and at an angle of 24.9 degrees, resulting in an impact severity of 116.3 kip-ft (157.7 kJ). At 0.197 sec after impact, the vehicle became parallel to the system with a speed of 52.4 mph (84.3 km/h). At 0.558 sec, the vehicle exited the system at a speed of 48.9 mph (78.7 km/h) and at an angle of 4.9 degrees. The vehicle was successfully contained and smoothly redirected.

Exterior vehicle damage was moderate. Interior occupant compartment deformations were minimal with a maximum of 1¾ in. (44 mm), which did not violate the limits established in MASH 2016. Damage to the barrier was also moderate, consisting of contact marks on the front face of the PCB segments, concrete spalling, and concrete cracking on barrier nos. 4 and 5. The maximum dynamic barrier deflection was 33.0 in. (838 mm), which included minor tipping of the barrier at the top surface. The working width of the PCB system was 57.0 in. (1,448 mm). All occupant risk measures were within the recommended limits, and the occupant compartment deformations were also deemed acceptable. Therefore, the box-beam stiffened, NJDOT barriers, Type 4 (Alternative B), corresponding to connection type B in the 2015 NJDOT *Roadway Design Manual*, successfully met all the safety performance criteria of MASH 2016 test designation no. 3-11.

The box-beam stiffened, NJDOT PCB, Type 4 (Alternative B), joined with a connection key, joint slack removed, grouted toes, barrier nos. 1 and 10 pinned on both the traffic side and back side, and box beam section installed across all joints, corresponding to connection type B in the 2015 NJDOT *Roadway Design Manual*, was successfully crash tested and evaluated according to the AASHTO MASH 2016 TL-3 criteria. This barrier successfully met all the requirements of MASH 2016 test designation no. 3-11. In addition, the researchers consider the system MASH 2016 compliant based on the successful test designation no. 3-11 test and the previous justification for test designation no. 3-10 being deemed not critical.

A comparison of similar box-beam stiffened systems included two systems: (1) a NJ PCB system with box beam bolted across all barrier joints, joint slack removed, and grouted toes (test no. NJPCB-5)] and (2) a New York PCB system with box beam bolted across only barrier joints from barrier nos. 4 through 7 and without removal of joint slack or grouted toes (test no. NYTCB-1) [16]. A review of these test results (test nos. NJPCB-5 and NYTCB-1) revealed little to no benefit would be observed in reduced barrier deflections and clear space requirements for box-beam stiffened, free-standing PCBs due to joint slack removal and/or use of grouted toes as dynamic deflections and the clear space behind barrier for both tests are very similar. The finding is primarily due to no barrier reinforcement in the toes of both the New York and New Jersey PCB segments. The lack of steel reinforcement led to concrete fracture near the barrier toes when they were loaded by adjacent barrier segments, which caused increased rotation of the barrier joints. This concrete toe disengagement reduced the expected benefit that would have been provided by the removal of joint slack and use of grouted toes. Second, the PCB segments used in these tests have a relatively small gap between adjacent barrier segments. Thus, improvement of the joint response through removal of joint slack and use of grouted toes provided less benefit than would be expected for other PCB systems, which utilize joint spacings up to 4 in. (102 mm). Finally, barrier system behavior and associated barrier deflections can vary from test to test due to the natural variability of a wide variety of factors involved in full-scale crash testing. These factors would include slight differences in impact conditions, differing test vehicle model years, slight variations in steel and concrete strengths, and variation of the cracking and damage observed on the barrier segments, among others. Thus, some variability would be expected in barrier performance even for basically identical systems.

In both the 2013 and 2015 NJDOT *Roadway Design Manual*, the allowable deflection is determined by the clear space behind the barrier, which is defined as the maximum deflection of the back of the barrier from its original position. For connection type B, as specified in the 2015 NJDOT *Roadway Design Manual* and utilized in this system, the NJDOT allowable deflection guidance is 28 in. (711 mm). For this test, the clear space behind the barrier was 33.0 in. (838 mm). Limited reductions in PCB deflections and clear space behind the barrier were observed with joint slack removal and use of grouted toes. Again, this finding is primarily due to the fracture and disengagement of the barrier toes. If larger reductions in PCB deflections and clear space are desired, PCB redesign or modification would be required, including reinforcement of the barrier toes, which may improve the effectiveness of joint slack removal and the use of grouted toes.

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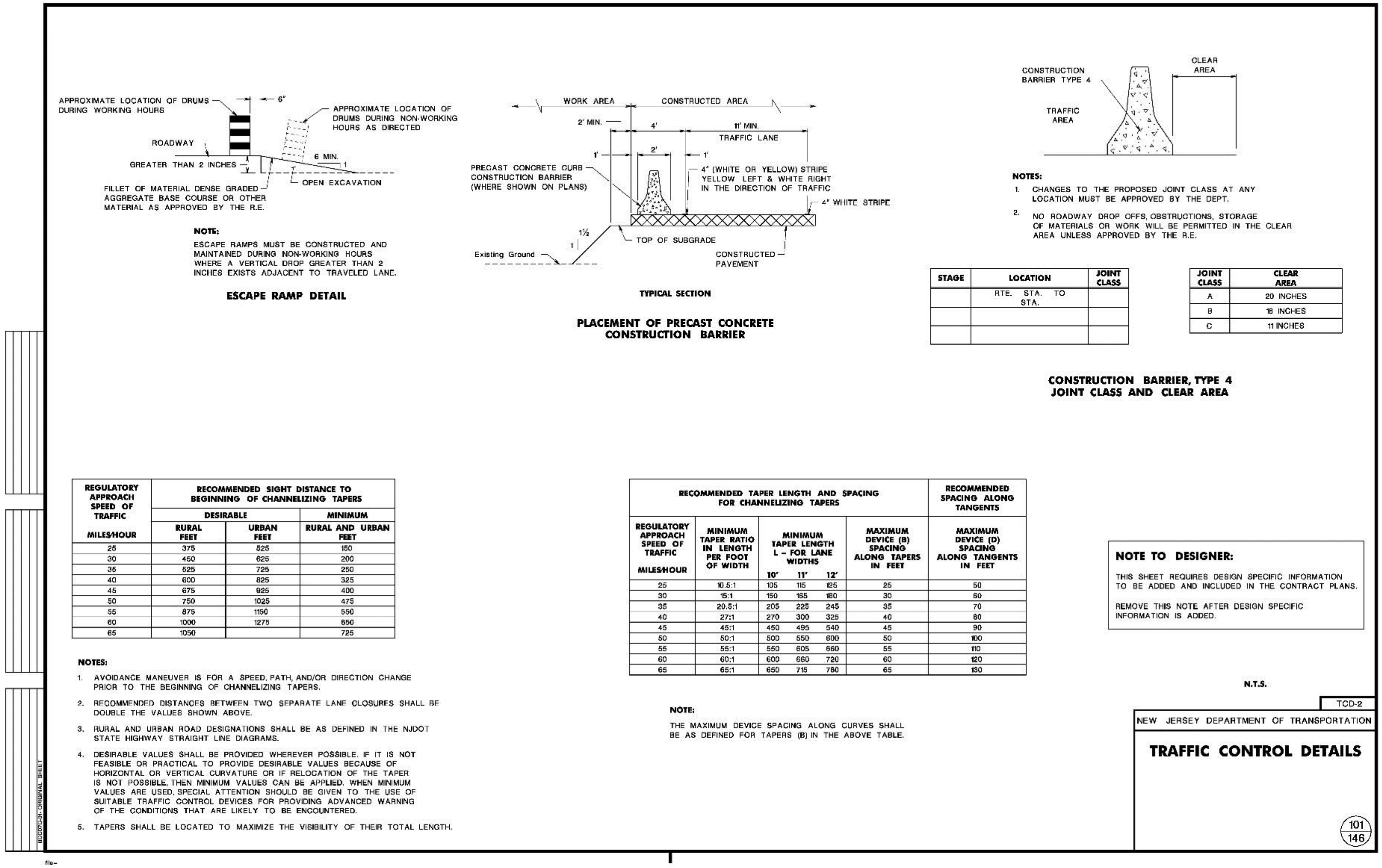
12 APPENDICES

Appendix A. NJDOT PCB Standard Plans



REGULATORY APPROACH SPEED OF TRAFFIC	RECOMMENDED SIGHT DISTANCE TO BEGINNING OF CHANNELIZING TAPERS		
	DESIRABLE		MINIMUM
MILES/HOUR	RURAL FEET	URBAN FEET	RURAL AND URBAN FEET
25	375	525	150
30	450	625	200
35	525	725	250
40	600	825	325
45	675	925	400
50	750	1025	475
55	875	1150	550
60	1000	1275	650
65	1050		725

RECOMMENDED TAPER LENGTH AND SPACING FOR CHANNELIZING TAPERS						RECOMMENDED SPACING ALONG TANGENTS
REGULATORY APPROACH SPEED OF TRAFFIC MILES/HOUR	MINIMUM TAPER RATIO IN LENGTH PER FOOT OF WIDTH	MINIMUM TAPER LENGTH L – FOR LANE WIDTHS			MAXIMUM DEVICE (B) SPACING ALONG TAPERS IN FEET	MAXIMUM DEVICE (D) SPACING ALONG TANGENTS IN FEET
		10'	11'	12'		
25	10.5:1	105	115	125	25	50
30	15:1	150	165	180	30	60
35	20.5:1	205	225	245	35	70
40	27:1	270	300	325	40	80
45	45:1	450	495	540	45	90
50	50:1	500	550	600	50	100
55	55:1	550	605	660	55	110
60	60:1	600	660	720	60	120
65	65:1	650	715	780	65	130

Figure A-1. NJDOT PCB Standard Plans

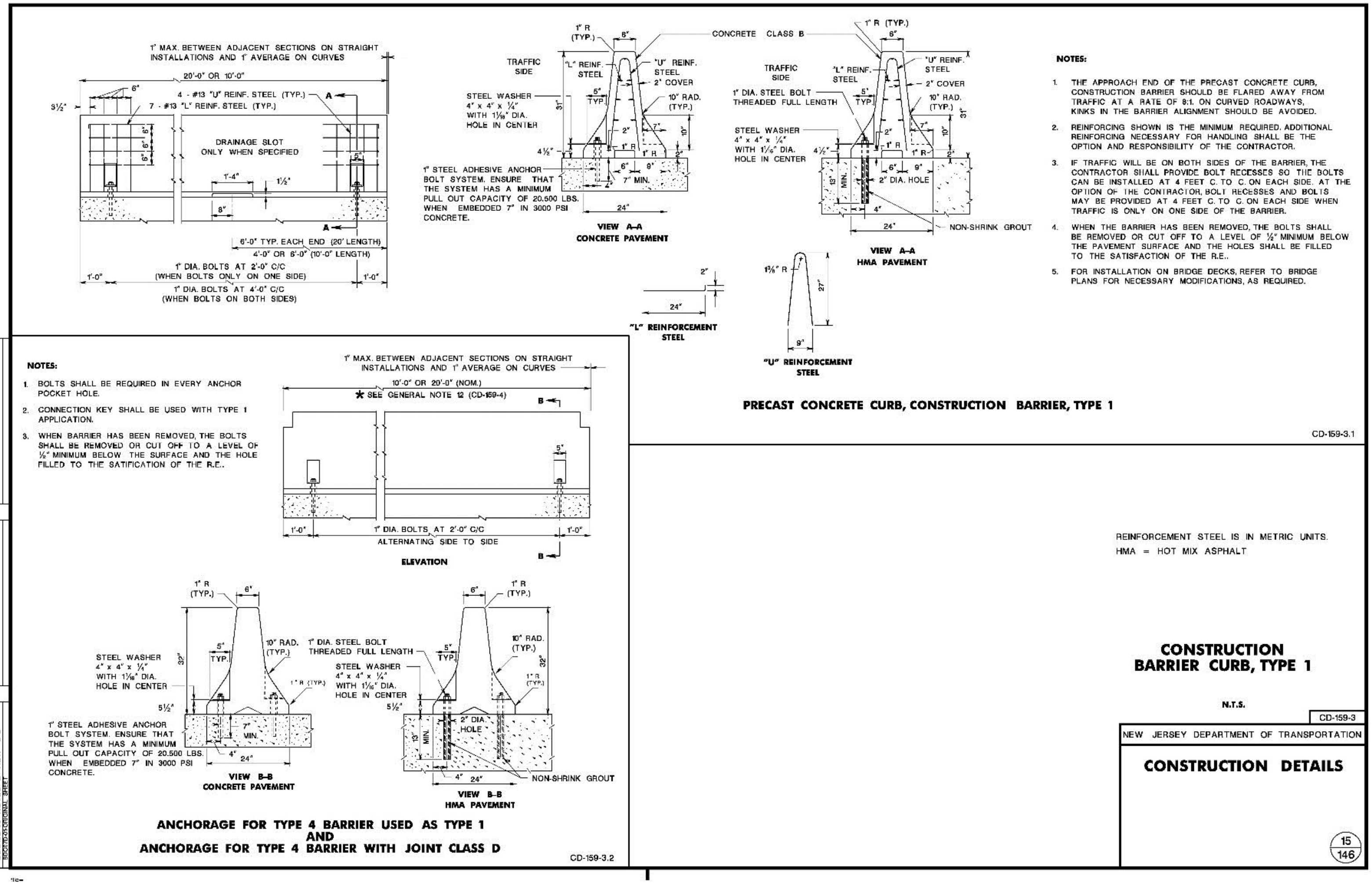


Figure A-2. NJDOT PCB Standard Plans

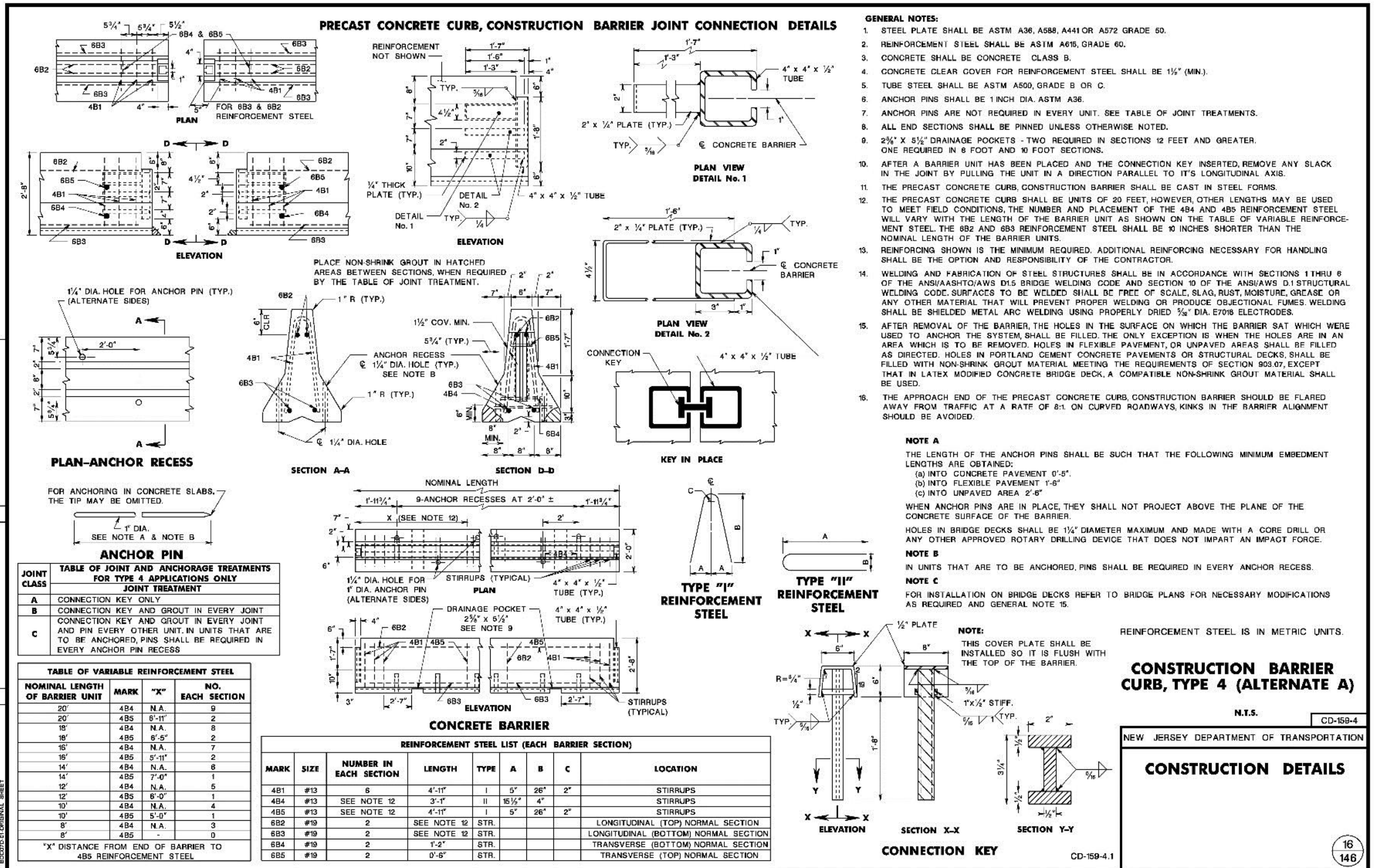


Figure A-3. NJDOT PCB Standard Plans

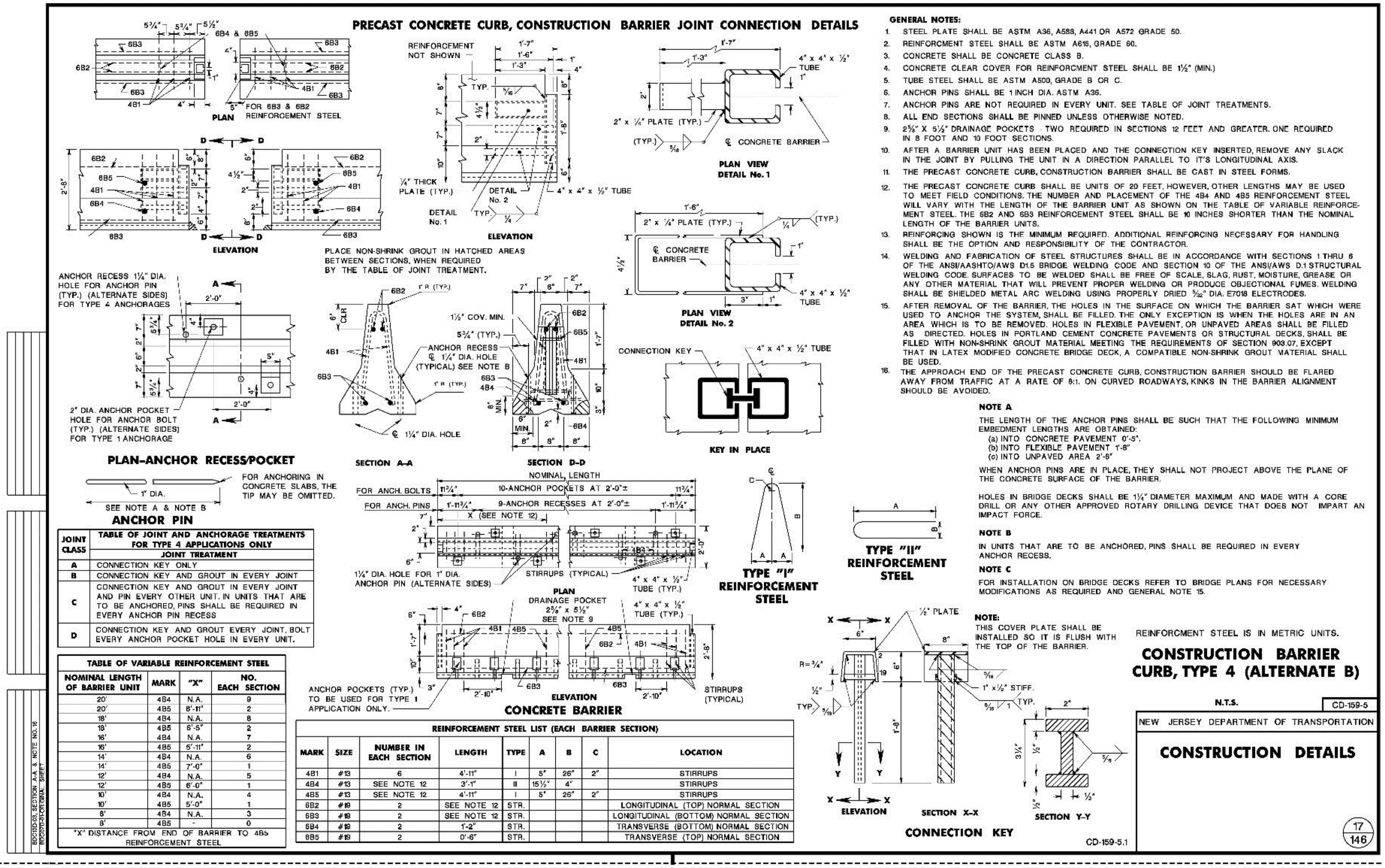


Figure A-4. NJDOT PCB Standard Plans

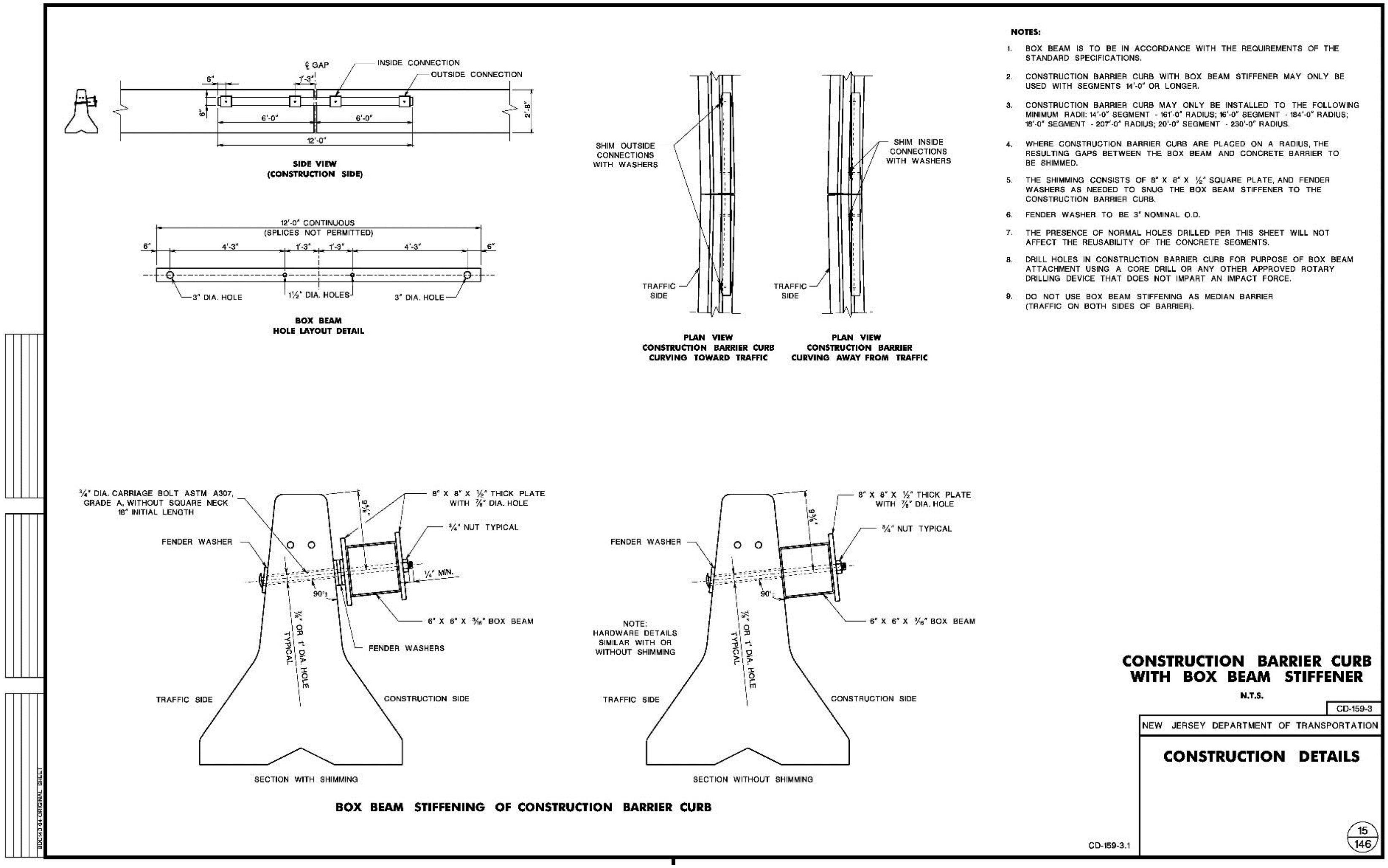


Figure A-5. NJDOT PCB Standard Plans

Appendix B. Material Specifications

Table B-1. Bill of Materials, Test No. NJPCB-5

Item No.	Description	Material Specification	Reference
a1	Concrete Barrier Segment	Min. f 'c = 3,700 psi (25.5 MPa)	University of Nebraska 15-563
a2	Anchor Steel Pins	ASTM A36	Heat #54141812
b1	Rebar - #4 Vertical Stirrup	ASTM A615 Gr. 60	Heat #61101274, 61101493, 61101510, 61101492, 61101499, 61101772
b2, b3	Rebar - #6 Longitudinal Bar	ASTM A615 Gr. 60	Heat #6115448, 61105472
b4	Rebar - #4 Horizontal Anchor Recess, Reinforcement Stirrup	ASTM A615 Gr. 60	Heat #61101274, 61101493, 61101510, 61101492, 61101499, 61101772
b5	Rebar - #6 Top & Bottom Cross Bar	ASTM A615 Gr. 60	Heat #6115448, 61105472
c1	Steel Tube – 4”×4”×½” (102×102×12.7) thick × 20” (508) long	ASTM A500 Gr. B and C	Heat #821597, 1422428, M04495_1, T83539, SD5020
c2	Bent Steel Plate 1, 2”×¼” (51×6)	ASTM A36	Heat #1129849
c3	Bent Steel Plate 2, 2”×¼” (51×6)	ASTM A36	Heat #1129849
d1	Steel Plate 1, 2”×½” (51×13)	ASTM A36	Heat #L99837
d2	Steel Plate 2, 2¼”×½” (57×13)	ASTM A36	Heat #54144612
d3	½” (13) Steel Plate – Stiffener	ASTM A36	Heat #54144612, L99837
d4	½” (13) Steel Plate – Top Plate	ASTM A36	Heat #54144612, L99837
e1	Non-Shrink Grout	Min. 1-day Compressive Strength 1,000 psi (6.9 MPa)	Advantage Grout ASTM C1107 Product Code: 67435 Report No. 2147369001
f1	Box Beam Stiffener, 6”×6”×$^{3}/_{16}$” (152×152×5) × 144” (3,658) long	ASTM A500 Gr. C	Heat #B38461
f2	Steel Plate, 8”×8”×½” (203×203×13)	ASTM A36	Heat #T3079
f3	Bolts and Nuts, ¾” (19) dia. × 17” (432) long carriage bolt without square neck	Bolts – ASTM A307 Gr. A, Nuts – ASTM A563A	Heat #529615 Heat #G420007618
f4	Fender Washer, ¾” (19) dia.	ASTM F844	-

UNIVERSITY OF NEBRASKA

15-563

Cast Date	Age (days)	Cylinder 1	Cylinder 2	Average	Age (days)	Cylinder 1	Cylinder 2	Average	Age (days)	Cylinder 1	Cylinder 2	Average	Air	Slump	Concrete Temp.	Ambient Temp	EMAIL, Mailed, etc
10/26/2015	1	4171	3869	4020	7	7805	7800	7803	28			0	5.5	6 3/4	60	58	
10/27/2015	1	3539	3883	3711	7	7343	7624	7484	28			0	6.8	5 3/4	62	60	
10/28/2015	1	4116	4311	4214	7	6223	6340	6282	28			0	6.0	6 1/2	64	64	
10/29/2015	1	3831	3544	3688	7	7046	6998	7022	28			0	5.8	6 1/2	67	68	
10/30/2015	3	4571	4608	4590	7	6337	6235	6286	28			0	6.0	6 1/2	64	63	
11/2/2015	1	3125	3062	3094	7	6887	6748	6818	28			0	6.2	5 3/4	64	62	
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
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	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					

Figure B-2. Concrete Barrier Segment – Concrete Strength, Test No. NJPCB-5

CERTIFIED MATERIAL TEST REPORT Page 1/1

GERDAU

US-ML-CHARLOTTE
6601 LAKEVIEW ROAD
CHARLOTTE, NC 28269
USA

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE	
STEEL & PIPE SUPPLY CO INC JONESBURG INDUSTRIAL PARK JONESBURG,MO 63351 USA	STEEL & PIPE SUPPLY CO INC MANHATTAN,KS 66505-1688 USA	A36/44W	Round Bar / 1"	
		LENGTH: 20'00"	WEIGHT: 14,968 LB	HEAT / BATCH: 54141812/02
SALES ORDER: 1384530/000040	CUSTOMER MATERIAL N°: 000000000009010020	SPECIFICATION / DATE or REVISION: 1-ASTM A6/A6M-11, A36/A36M-08 2-A709/A709M-11 GR36 3-CSA G40.21-04(R2009) 44W		

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
4500233654	1321-0000027245	12/18/2014

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	V %	Nb %	Sn %
0.17	0.69	0.018	0.031	0.19	0.41	0.13	0.11	0.030	0.001	0.001	0.014

MECHANICAL PROPERTIES

Elong. %	G/L Inch	UTS PSI	UTS MPa	YS PSI	YS MPa
23.20	8.000	77428	534	54195	374

GEOMETRIC CHARACTERISTICS

R:R
32.00

COMMENTS / NOTES

R#16-0230 ASTM A36 1"x15" Round Bar

New Jersey TCB Barrer Anchor Dowel Pins

H#54141812 R#16-0230 December 2015

The above figures are certified chemical and physical test records as contained in the permanent records of company. We certify that these data are correct and in compliance with specified requirements. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

BHASKAR YALAMANCHILI
QUALITY DIRECTOR

JORDAN FOSTER
QUALITY ASSURANCE MGR.

Figure B-3. Anchor Pins Material Certificate, Test No. NJPCB-5

GERDAU

US-ML-SAYREVILLE
NORTH CROSSMAN ROAD
SAYREVILLE, NJ 08872
USA

CERTIFIED MATERIAL TEST REPORT

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CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE
RE STEEL SUPPLY CO INC 2000 EDDYSTONE INDUSTRIAL PARK EDDYSTONE,PA 19022 USA	RE STEEL SUPPLY CO INC 2000 EDDYSTONE INDUSTRIAL PARK EDDYSTONE,PA 19022-1588 USA	60 (420)	Rebar / #4 (13MM)

LENGTH	WEIGHT	HEAT / BATCH
40'00"	5,050 LB	61101274/02

SALES ORDER	CUSTOMER MATERIAL N°	SPECIFICATION / DATE or REVISION
1785955/000010		ASTM A615/A615M-14

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
BB 22777	1331-0000029243	01/23/2015

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	CEqyA706 %
0.43	0.66	0.012	0.048	0.23	0.43	0.16	0.05	0.046	0.019	0.017	0.56

MECHANICAL PROPERTIES

YS PSI	YS MPa	UTS PSI	UTS MPa	G/L Inch	G/L mm
66850	461	93950	648	8.000	200.0
67400	465	95100	656	8.000	200.0

MECHANICAL PROPERTIES

Elong. %	BendTest
13.50	OK
13.50	OK

GEOMETRIC CHARACTERISTICS

%Light %	Def Hgt Inch	Def Gap Inch	DefSpace Inch
4.10	0.030	0.099	0.320
3.20	0.030	0.099	0.320

COMMENTS / NOTES

This grade meets the requirements for the following grades:

The above figures are certified chemical and physical test records as contained in the permanent records of company. We certify that these data are correct and in compliance with specified requirements. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

BHASKAR YALAMANCHILI
QUALITY DIRECTOR

JOSEPH T HOMIC
QUALITY ASSURANCE MGR.

Figure B-4. Rebar No. 4 Material Certificate, Test No. NJPCB-5

CERTIFIED MATERIAL TEST REPORT

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GERDAU

US-ML-SAYREVILLE
NORTH CROSSMAN ROAD
SAYREVILLE, NJ 08872
USA

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE
RE STEEL SUPPLY CO INC 2000 EDDYSTONE INDUSTRIAL PARK EDDYSTONE,PA 19022 USA	RE STEEL SUPPLY CO INC 2000 EDDYSTONE INDUSTRIAL PARK EDDYSTONE,PA 19022-1588 USA	60 (420)	Rebar / #4 (13MM)

LENGTH	WEIGHT	HEAT / BATCH
40'00"	5,023 LB	61101493/04

SALES ORDER	CUSTOMER MATERIAL N°	SPECIFICATION / DATE or REVISION
1785955/000010		ASTM A615/A615M-14

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
BB 22777	1331-0000029243	01/23/2015

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	CEqyA706 %
0.42	0.65	0.012	0.058	0.19	0.43	0.15	0.09	0.056	0.020	0.009	0.56

MECHANICAL PROPERTIES

YS PSI	YS MPa	UTS PSI	UTS MPa	G/L Inch	G/L mm
71350	492	104900	723	8.000	200.0
71250	491	105600	728	8.000	200.0

MECHANICAL PROPERTIES

Elong. %	BendTest
13.00	OK
11.50	OK

GEOMETRIC CHARACTERISTICS

%Light %	Def Hgt Inch	Def Gap Inch	DefSpace Inch
2.70	0.032	0.038	0.321
1.40	0.034	0.039	0.321

COMMENTS / NOTES

This grade meets the requirements for the following grades:

The above figures are certified chemical and physical test records as contained in the permanent records of company. We certify that these data are correct and in compliance with specified requirements. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

BHASKAR YALAMANCHILI
QUALITY DIRECTOR

JOSEPH T HOMOC
QUALITY ASSURANCE MGR.

Figure B-5. Rebar No. 4 Material Certificate, Test No. NJPCB-5

GERDAU

US-ML-SAYREVILLE
NORTH CROSSMAN ROAD
SAYREVILLE, NJ 08872
USA

CERTIFIED MATERIAL TEST REPORT

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CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE
RE STEEL SUPPLY CO INC 2000 EDDYSTONE INDUSTRIAL PARK EDDYSTONE,PA 19022 USA	RE STEEL SUPPLY CO INC 2000 EDDYSTONE INDUSTRIAL PARK EDDYSTONE,PA 19022-1588 USA	60 (420)	Rebar / #4 (13MM)

LENGTH	WEIGHT	HEAT / BATCH
40'00"	5,050 LB	61101510/03

SALES ORDER	CUSTOMER MATERIAL Nº	SPECIFICATION / DATE or REVISION
1785955/000010		ASTM A615/A615M-14

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
BB 22777	1331-0000029243	01/23/2015

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	CEqyA706 %
0.42	0.66	0.018	0.046	0.21	0.30	0.11	0.06	0.035	0.018	0.015	0.55

MECHANICAL PROPERTIES

YS PSI	YS MPa	UTS PSI	UTS MPa	G/L Inch	G/L mm
73400	506	107150	739	8.000	200.0
75600	521	110500	762	8.000	200.0

MECHANICAL PROPERTIES

Elong. %	BendTest
12.00	OK
13.00	OK

GEOMETRIC CHARACTERISTICS

%Light %	Def Hgt Inch	Def Gap Inch	DefSpace Inch
2.40	0.032	0.080	0.322
2.30	0.032	0.080	0.322

COMMENTS / NOTES

This grade meets the requirements for the following grades:

The above figures are certified chemical and physical test records as contained in the permanent records of company. We certify that these data are correct and in compliance with specified requirements. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

BHASKAR YALAMANCHILI
QUALITY DIRECTOR

JOSEPH T HOMIC
QUALITY ASSURANCE MGR.

Figure B-6. Rebar No. 4 Material Certificate, Test No. NJPCB-5

GERDAU

CERTIFIED MATERIAL TEST REPORT

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US-ML-SAYREVILLE
NORTH CROSSMAN ROAD
SAYREVILLE, NJ 08872
USA

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE
RE STEEL SUPPLY CO INC 2000 EDDYSTONE INDUSTRIAL PARK EDDYSTONE,PA 19022 USA	RE STEEL SUPPLY CO INC 2000 EDDYSTONE INDUSTRIAL PARK EDDYSTONE,PA 19022-1588 USA	60 (420)	Rebar / #4 (13MM)

LENGTH	WEIGHT	HEAT / BATCH
40'00"	10,020 LB	**61101492/02**

SALES ORDER	CUSTOMER MATERIAL N°	SPECIFICATION / DATE or REVISION
1785955/000010		ASTM A615/A615M-14

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
BB 22777	1331-0000029243	01/23/2015

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	CEqyA706 %
0.43	0.67	0.014	0.054	0.20	0.43	0.21	0.10	0.064	0.018	0.017	0.57

MECHANICAL PROPERTIES

YS PSI	YS MPa	UTS PSI	UTS MPa	G/L Inch	G/L mm
65150	449	96100	663	8.000	200.0
68450	472	99600	687	8.000	200.0

MECHANICAL PROPERTIES

Elong. %	BendTest
15.00	OK
15.50	OK

GEOMETRIC CHARACTERISTICS

%Light %	Def Hgt Inch	Def Gap Inch	DefSpace Inch
3.60	0.031	0.078	0.322
1.70	0.029	0.090	0.322

COMMENTS / NOTES

This grade meets the requirements for the following grades:

The above figures are certified chemical and physical test records as contained in the permanent records of company. We certify that these data are correct and in compliance with specified requirements. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

BHASKAR YALAMANCHILI
QUALITY DIRECTOR

JOSEPH T HOMIC
QUALITY ASSURANCE MGR.

Figure B-7. Rebar No. 4 Material Certificate, Test No. NJPCB-5

GERDAU

CERTIFIED MATERIAL TEST REPORT

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US-ML-SAYREVILLE
NORTH CROSSMAN ROAD
SAYREVILLE, NJ 08872
USA

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE
RE STEEL SUPPLY CO INC 2000 EDDYSTONE INDUSTRIAL PARK EDDYSTONE,PA 19022 USA	RE STEEL SUPPLY CO INC 2000 EDDYSTONE INDUSTRIAL PARK EDDYSTONE,PA 19022-1588 USA	60 (420)	Rebar / #4 (13MM)

LENGTH	WEIGHT	HEAT / BATCH
40'00"	5,050 LB	61101499/04

SALES ORDER	CUSTOMER MATERIAL N°	SPECIFICATION / DATE or REVISION
1785955/000010		ASTM A615/A615M-14

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
BB 22777	1331-0000029243	01/23/2015

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	CEqyA706 %
0.43	0.68	0.026	0.064	0.21	0.33	0.21	0.19	0.066	0.016	0.012	0.58

MECHANICAL PROPERTIES

YS PSI	YS MPa	UTS PSI	UTS MPa	G/L Inch	G/L mm
70900	489	105500	727	8.000	200.0
68950	475	103200	712	8.000	200.0

MECHANICAL PROPERTIES

Elong. %	BendTest
11.00	OK
11.00	OK

GEOMETRIC CHARACTERISTICS

%Light %	Def Hgt Inch	Def Gap Inch	DefSpace Inch
1.90	0.032	0.088	0.321
1.90	0.032	0.086	0.321

COMMENTS / NOTES

This grade meets the requirements for the following grades:

The above figures are certified chemical and physical test records as contained in the permanent records of company. We certify that these data are correct and in compliance with specified requirements. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

BHASKAR YALAMANCHILI
QUALITY DIRECTOR

JOSEPH T HOMIC
QUALITY ASSURANCE MGR.

Figure B-8. Rebar No. 4 Material Certificate, Test No. NJPCB-5

GERDAU

CERTIFIED MATERIAL TEST REPORT

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US-ML-SAYREVILLE
NORTH CROSSMAN ROAD
SAYREVILLE, NJ 08872
USA

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE
RE STEEL SUPPLY CO INC 2000 EDDYSTONE INDUSTRIAL PARK EDDYSTONE,PA 19022 USA	RE STEEL SUPPLY CO INC 2000 EDDYSTONE INDUSTRIAL PARK EDDYSTONE,PA 19022-1588 USA	60 (420)	Rebar / #4 (13MM)

LENGTH	WEIGHT	HEAT / BATCH
40'00"	4,008 LB	61101772/04

SALES ORDER	CUSTOMER MATERIAL N°	SPECIFICATION / DATE or REVISION
1785955/000010		ASTM A615/A615M-14

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
BB 22777	1331-0000029243	01/23/2015

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	CEqyA706 %
0.44	0.67	0.019	0.059	0.20	0.38	0.16	0.06	0.047	0.017	0.016	0.57

MECHANICAL PROPERTIES

YS PSI	YS MPa	UTS PSI	UTS MPa	G/L Inch	G/L mm
66400	458	96900	668	8.000	200.0
65850	454	97700	674	8.000	200.0

MECHANICAL PROPERTIES

Elong. %	BendTest
16.00	OK
17.00	OK

GEOMETRIC CHARACTERISTICS

%Light %	Def Hgt Inch	Def Gap Inch	DefSpace Inch
1.10	0.025	0.099	0.320
0.80	0.029	0.115	0.320

COMMENTS / NOTES

This grade meets the requirements for the following grades:

The above figures are certified chemical and physical test records as contained in the permanent records of company. We certify that these data are correct and in compliance with specified requirements. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

BHASKAR YALAMANCHILI
QUALITY DIRECTOR

JOSEPH T HOMIC
QUALITY ASSURANCE MGR.

Figure B-9. Rebar No. 4 Material Certificate, Test No. NJPCB-5

CERTIFIED MATERIAL TEST REPORT

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GERDAU

US-ML-SAYREVILLE
NORTH CROSSMAN ROAD
SAYREVILLE, NJ 08872
USA

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE
RE STEEL SUPPLY CO INC 2000 EDDYSTONE INDUSTRIAL PARK EDDYSTONE,PA 19022 USA	RE STEEL SUPPLY CO INC 2000 EDDYSTONE INDUSTRIAL PARK EDDYSTONE,PA 19022-1588 USA	60 (420)	Rebar / #6 (19MM)

LENGTH	WEIGHT	HEAT / BATCH
40'00"	30,282 LB	**61105448**/03

SALES ORDER	CUSTOMER MATERIAL N°	SPECIFICATION / DATE or REVISION
2886827/000020		ASTM A615/A615M-15

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
BB-23635	1331-0000038904	10/08/2015

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	CEqyA706 %
0.48	0.75	0.010	0.064	0.23	0.33	0.18	0.09	0.036	0.028	0.018	0.65

MECHANICAL PROPERTIES

YS PSI	YS MPa	UTS PSI	UTS MPa	G/L Inch	G/L mm
70159	484	107318	740	8.000	200.0
70590	487	108364	747	8.000	200.0

MECHANICAL PROPERTIES

Elong. %	BendTest
14.00	OK
13.00	OK

GEOMETRIC CHARACTERISTICS

%Light %	Def Hgt Inch	Def Gap Inch	DefSpace Inch
5.80	0.040	0.090	0.477
5.80	0.040	0.090	0.477

COMMENTS / NOTES

The above figures are certified chemical and physical test records as contained in the permanent records of company. We certify that these data are correct and in compliance with specified requirements. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

BHASKAR YALAMANCHILI
QUALITY DIRECTOR

JOSEPH T HOMIC
QUALITY ASSURANCE MGR.

Figure B-10. Rebar No. 6 Material Certificate, Test No. NJPCB-5

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CERTIFIED MATERIAL TEST REPORT

GERDAU

US-ML-SAYREVILLE
NORTH CROSSMAN ROAD
SAYREVILLE, NJ 08872
USA

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE
RE STEEL SUPPLY CO INC 2000 EDDYSTONE INDUSTRIAL PARK EDDYSTONE,PA 19022 USA	RE STEEL SUPPLY CO INC 2000 EDDYSTONE INDUSTRIAL PARK EDDYSTONE,PA 19022-1588 USA	60 (420)	Rebar / #6 (19MM)

LENGTH	WEIGHT	HEAT / BATCH
40'00"	4,987 LB	**61105472**/03

SALES ORDER	CUSTOMER MATERIAL N°	SPECIFICATION / DATE or REVISION
2886827/000020		ASTM A615/A615M-15

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
BB-23635	1331-0000038904	10/08/2015

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	CEqyA706 %
0.46	0.72	0.019	0.048	0.21	0.38	0.15	0.14	0.036	0.017	0.022	0.63

MECHANICAL PROPERTIES

YS PSI	YS MPa	UTS PSI	UTS MPa	G/L Inch	G/L mm
73296	505	106977	738	8.000	200.0
73386	506	107455	741	8.000	200.0

MECHANICAL PROPERTIES

Elong. %	BendTest
13.00	OK
15.00	OK

GEOMETRIC CHARACTERISTICS

%Light %	Def Hgt Inch	Def Gap Inch	DefSpace Inch
4.20	0.058	0.072	0.481
4.50	0.058	0.072	0.481

COMMENTS / NOTES

The above figures are certified chemical and physical test records as contained in the permanent records of company. We certify that these data are correct and in compliance with specified requirements. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

BHASKAR YALAMANCHILI
QUALITY DIRECTOR

JOSEPH T HOMIC
QUALITY ASSURANCE MGR.

Figure B-11. Rebar No. 6 Material Certificate, Test No. NJPCB-5

Customer Name	Customer PO#	Shipper No	Heat Number
Seibel Modern Mfg.	Leon	273924	821597

Atlas Tube Canada ULC
200 Clark St.
Harrow, Ontario, Canada
N0R 1G0
Tel: 519-738-3541
Fax: 519-738-3537

Atlas Tube
JMC STEEL GROUP

Ref.B/L: 80664351
Date: 05.08.2015
Customer: 1497

MATERIAL TEST REPORT

Sold to
Triad Metals International
1 Village Road
HORSHAM PA 19044-3812
USA

Shipped to
Triad Metals International
3507 Grand Avenue
PITTSBURGH PA 15225
USA

Material: 3.0x3.0x125x24'0"0(7x7). Material No: 300301252400 Made In: Canada
Sales order: 989576 Purchase Order: 75461 Melted in: Canada

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
821195	0.190	0.810	0.009	0.007	0.019	0.044	0.060	0.006	0.006	0.026	0.045	0.002	0.002	0.000	0.003

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE
M101451859	49	063780 Psi	077160 Psi	26.6 %	ASTM A500-13 GRADE B&C	0.34

Material Note:
Sales Or.Note:

Material: 4.0x4.0x500x40'0"0(4x2). Material No: 400405004000 Made in: Canada
Sales order: 995107 Purchase Order: 76312 Melted in: Canada

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
775533	0.200	0.810	0.012	0.010	0.015	0.031	0.032	0.006	0.002	0.011	0.032	0.002	0.002	0.000	0.003

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE
M101454130	1	066980 Psi	075080 Psi	27.0 %	ASTM A500-13 GRADE B&C	0.35

Material Note:
Sales Or.Note:

Material: 4.0x4.0x500x40'0"0(4x2). Material No: 400405004000 Made in: Canada
Sales order: 995107 Purchase Order: 76312 Melted in: Canada

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
821597	0.210	0.780	0.011	0.009	0.013	0.040	0.026	0.006	0.004	0.013	0.031	0.002	0.002	0.000	0.004

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE
M101454130	7	069700 Psi	078390 Psi	27.2 %	ASTM A500-13 GRADE B&C	0.35

Material Note:
Sales Or.Note:

Marvin Phillips

Authorized by Quality Assurance:
The results reported on this report represent the actual attributes of the material furnished and indicate full compliance with all applicable specification and contract requirements.
CE calculated using the AWS D1.1 method.

Steel Tube Institute OF NORTH AMERICA

Page : 1 Of 4

Metals Service Center Institute

Figure B-12. Steel Tube Material Certificate, Test No. NJPCB-5

Customer Name	Customer PO#	Shipper No	Heat Number
Seibel Modern Mfg.	Leon	273924	821597

Atlas Tube Canada ULC
200 Clark St.
Harrow, Ontario, Canada
N0R 1G0
Tel: 519-738-3541
Fax: 519-738-3537

Atlas *Tube*
JMC STEEL GROUP

Ref.B/L: 80664351
Date: 05.08.2015
Customer: 1497

MATERIAL TEST REPORT

Sold to
Triad Metals International
1 Village Road
HORSHAM PA 19044-3812
USA

Shipped to
Triad Metals International
3507 Grand Avenue
PITTSBURGH PA 15225
USA

Material: 4.0x4.0x500x40'0"0(4x2). Material No: 400405004000 Made in: Canada
Sales order: 995107 Purchase Order: 76312 Melted in: Canada

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
821597	0.210	0.780	0.011	0.009	0.013	0.040	0.026	0.006	0.004	0.013	0.031	0.002	0.002	0.000	0.004

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE
M101454131	8	069700 Psi	078390 Psi	27.2 %	ASTM A500-13 GRADE B&C	0.35

Material Note:
Sales Or.Note:

Material: 6.0x2.0x188x24'0"0(3x9). Material No: 600201882400 Made in: Canada
Sales order: 995107 Purchase Order: 76312 Melted in: Canada

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
821679	0.180	0.790	0.010	0.008	0.015	0.040	0.047	0.002	0.005	0.023	0.038	0.002	0.002	0.000	0.004

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE
M101453723	27	058410 Psi	069080 Psi	33.3 %	ASTM A500-13 GRADE B&C	0.33

Material Note:
Sales Or.Note:

Material: 6.0x6.0x188x40'0"0(3x3). Material No: 600601884000 Made in: Canada
Sales order: 1001173 Purchase Order: 77498 Melted in: Canada

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
821531	0.190	0.810	0.013	0.006	0.017	0.059	0.051	0.005	0.004	0.015	0.036	0.002	0.002	0.000	0.004

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE
M101456164	9	063160 Psi	078380 Psi	30.5 %	ASTM A500-13 GRADE B&C	0.34

Material Note:
Sales Or.Note:

Authorized by Quality Assurance:
The results reported on this report represent the actual attributes of the material furnished and indicate full compliance with all applicable specification and contract requirements.
Calculated using the AWS D1.1 method.

Steel Tube Institute OF NORTH AMERICA

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Metals Service Center Institute

Figure B-13. Steel Tube Material Certificate, Test No. NJPCB-5

Customer Name	Customer PO#	Shipper No	Heat Number
Seibel Modern Mfg.	Leon	273924	1422428

Atlas ABC Corp (Atlas Tube Chicago)
1855 East 122nd Street
Chicago, Illinois, USA
60633
Tel: 773-646-4500
Fax: 773-646-6128

Atlas Tube
JMC STEEL GROUP

Ref.B/L: 80660765
Date: 04.15.2015
Customer: 1497

MATERIAL TEST REPORT

Sold to
Triad Metals International
1 Village Road
HORSHAM PA 19044-3812
USA

Shipped to
Triad Metals International
3507 Grand Avenue
PITTSBURGH PA 15225
USA

Material: 4.0x4.0x500x40'0"0(4x2). Material No: 400405004000 Made in: USA
Sales order: 989623 Purchase Order: 75462 Melted in: Russian Fed.

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
1422428	0.200	0.930	0.007	0.010	0.013	0.043	0.040	0.000	0.000	0.020	0.030	0.000	0.000	0.000	0.006

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE
M800549020	3	070619 Psi	081004 Psi	36 %	ASTM A500-13 GRADE B&C	0.37

Material Note:
Sales Or.Note:

Material: 4.0x4.0x500x40'0"0(4x2). Material No: 400405004000 Made in: USA
Sales order: 989623 Purchase Order: 75462 Melted in: Russian Fed.

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
1422428	0.200	0.930	0.007	0.010	0.013	0.043	0.040	0.000	0.000	0.020	0.030	0.000	0.000	0.000	0.006

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE
M800549017	8	070619 Psi	081004 Psi	36 %	ASTM A500-13 GRADE B&C	0.37

Material Note:
Sales Or.Note:

Material: 20.0x4.0x313x48'0"0(1x4). Material No: 2000403134800 Made in: USA
Sales order: 994677 Purchase Order: 75051-replacement Melted in: USA

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
A73575	0.200	0.490	0.009	0.002	0.030	0.034	0.120	0.000	0.020	0.060	0.050	0.001	0.002	0.000	0.009

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE
M900754817	4	057121 Psi	074148 Psi	30 %	ASTM A500-13 GRADE B&C	0.31

Material Note:
Sales Or.Note:

Authorized by Quality Assurance:
The results reported on this report represent the actual attributes of the material furnished and indicate full compliance with all applicable specification and contract requirements.
Calculated using the AWS D1.1 method.

Steel Tube Institute OF NORTH AMERICA

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Metals Service Center Institute

Figure B-14. Steel Tube Material Certificate, Test No. NJPCB-5

Customer Name	Customer PO#	Shipper No	Heat Number
Seibel Modern Mfg.	Leon	273924	M04495_1

Atlas ABC Corp (Atlas Tube Chicago)
1855 East 122nd Street
Chicago, Illinois, USA
60633
Tel: 773-646-4500
Fax: 773-646-6128

Atlas Tube
JMC STEEL GROUP

Ref.B/L: 80665303
Date: 05.18.2015
Customer: 1497

MATERIAL TEST REPORT

Sold to

Triad Metals International
1 Village Road
HORSHAM PA 19044-3812
USA

Shipped to

Triad Metals International
3507 Grand Avenue
PITTSBURGH PA 15225
USA

Material: 4.0x4.0x500x48'0"0(3x2). Material No: 400405004800 Made in: USA
Melted in: USA
Sales order: 989623 Purchase Order: 75462

Heat No	C	Mn	P	S	SI	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
M04495_1	0.190	0.750	0.014	0.010	0.019	0.050	0.050	0.004	0.004	0.010	0.040	0.001	0.001	0.000	0.005

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE: 0.33
M800554030	2	072918 Psi	082550 Psi	35 %	ASTM A500-13 GRADE B&C	

Material Note:
Sales Or.Note:

Authorized by Quality Assurance:
The results reported on this report represent the actual attributes of the material furnished and indicate full compliance with all applicable specification and contract requirements.
Calculated using the AWS D1.1 method.

Steel Tube Institute OF NORTH AMERICA

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Metals Service Center Institute

Figure B-15. Steel Tube Material Test Certificate, Test No. NJPCB-5

Customer Name	Customer PO#	Shipper No	Heat Number
Seibel Modern Mfg.	Leon	273924	T83539

Atlas ABC Corp (Atlas Tube Chicago)
1855 East 122nd Street
Chicago, Illinois, USA
60633
Tel: 773-646-4500
Fax: 773-646-6128

Atlas Tube
JMC STEEL GROUP

Ref.B/L: 80619794
Date: 08.22.2014
Customer: 1497

MATERIAL TEST REPORT

Sold to
Triad Metals International
1 Village Road
HORSHAM PA 19044-3812
USA

Shipped to
Triad Metals International
3500 Neville Road
NEVILLE ISLAND PA 15225
USA

Material: 4.0x4.0x375x48'0"0(4x2). Material No: 400403754800 Made in: USA
Melted in: USA
Sales order: 934921 Purchase Order: 67358

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
E84203	0.190	0.800	0.015	0.011	0.021	0.050	0.040	0.005	0.006	0.010	0.040	0.001	0.001	0.000	0.004

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE: 0.34
M800504131	8	071476 Psi	081675 Psi	32 %	ASTM A500-13 GRADE B&C	

Material Note:
Sales Or.Note:

Material: 4.0x4.0x500x40'0"0(4x2). Material No: 400405004000 Made in: USA
Melted in: USA
Sales order: 934921 Purchase Order: 67358

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
T83539	0.200	0.820	0.012	0.007	0.015	0.054	0.020	0.007	0.004	0.010	0.040	0.001	0.001	0.000	0.005

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE: 0.35
M800500342	8	072654 Psi	085933 Psi	29 %	ASTM A500-13 GRADE B&C	

Material Note:
Sales Or.Note:

Material: 12.0x12.0x250x40'0"0(2x2). Material No: 1201202504000 Made in: USA
Melted in: USA
Sales order: 933979 Purchase Order: 67228

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
T84047	0.180	0.800	0.008	0.007	0.015	0.045	0.020	0.003	0.003	0.010	0.040	0.001	0.001	0.000	0.007

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE: 0.33
M900697115	4	055286 Psi	073956 Psi	28 %	ASTM A500-13 GRADE B&C	

Material Note:
Sales Or.Note:

Marvin Phillips

Authorized by Quality Assurance:
The results reported on this report represent the actual attributes of the material furnished and indicate full compliance with all applicable specification and contract requirements.
CE calculated using the AWS D1.1 method.

Steel Tube Institute OF NORTH AMERICA

Page : 1 Of 4

Metals Service Center Institute

Figure B-16. Steel Tube Material Certificate, Test No. NJPCB-5

Customer Name	Customer PO#	Shipper No	Heat Number
Seibel Modern Mfg.	Leon	273924	SD5020

Independence Tube

6226 W. 74th St
Chicago, IL 60638
708-496-0380
Fax: 708-563-1950

independencetube.com
itctube.com
Certificate Number: DCR 250913

Sold By:
INDEPENDENCE TUBE CORPORATION
6226 W. 74th St.
Chicago, IL 60638
Tel: 708-496-0380
Fax: 708-563-1950

Purchase Order No: 70783
Sales Order No: DCR 64130 - 5
Bill of Lading No: DCR 43787 - 94
Invoice No:

Shipped: 1/16/2015
Invoiced:

Sold To:
2103 - TRIAD METALS
1 VILLAGE ROAD
HORSHAM, PA 19044-3812

Ship To:
39 - TRIAD METALS BARGE
MILE MARKER 7.3
OHIO RIVER
NEVILLE ISLAND, PA 15225

CERTIFICATE of ANALYSIS and TESTS

Customer Part No:

TUBING A500 GRADE B(C)
4" SQ X 1/2" X 48'

Certificate No: DCR 250913
Test Date: 1/14/2015

Total Pieces	Total Weight
36	37,376

Bundle Tag	Mill	Heat	Pieces	Weight
844458	40	SD5020	9	9,344
844459	40	SD5020	9	9,344
844460	40	SD5020	9	9,344
844461	40	SD5020	9	9,344

Mill #: 40 Heat #: SD5020 Yield: 72,300 psi Tensile: 78,800 psi Elongation: 28.50 % Y/T Ratio: 0.9175 Carbon Eq: 0.1352

C	Mn	P	S	Si	Al	Cu	Cr	Mo	V	Ni	Nb
0.0500	0.3900	0.0090	0.0040	0.2240	0.0260	0.0900	0.0400	0.0200	0.0010	0.0300	0.0080

Certification:

I certify that the above results are a true and correct copy of records prepared and maintained by Independence Tube Corporation. Sworn this day, 1/14/2015

WE PROUDLY MANUFACTURE ALL OF OUR HSS IN THE USA.
INDEPENDENCE TUBE PRODUCT IS MANUFACTURED, TESTED, AND INSPECTED IN ACCORDANCE WITH ASTM STANDARDS.

CURRENT STANDARDS:
..............................A500/A500M-13
..............................A513-12
..............................A252-10
..............................A847/A847M-12

Jose Martinez, QMS Manager

MATERIAL IDENTIFIED AS A500 GRADE B(C) MEETS BOTH ASTM A500 GRADE B AND A500 GRADE C SPECIFICATIONS.

Figure B-17. Steel Tube Material Certificate, Test No. NJPCB-5

MID-AMERICA STEEL CORPORATION
TEST REPORT

No. F33822

TO: SEIBEL MODERN MFG & WELDING

DATE: 02/19/13
P.O. #: SBJ-40

ATTN:

TAG#	SIZE	SPEC
K78419	1/4 x 48.000 x 144.000	A-36
K78420	1/4 x 48.000 x 144.000	A-36
K78421	1/4 x 48.000 x 144.000	A-36
K78422	1/4 x 48.000 x 144.000	A-36

CHEMICAL ANALYSIS

TAG#	HEAT#	C	Mn	P	S
K78419	1129849	0.063	0.760	0.012	0.004
K78420	1129849	0.063	0.760	0.012	0.004
K78421	1129849	0.063	0.760	0.012	0.004
K78422	1129849	0.063	0.760	0.012	0.004

PHYSICAL ANALYSIS

TAG#	HEAT#	TENSILE	YIELD	ELONGATION
K78419	1129849	75,102	58,422	26%
K78420	1129849	75,102	58,422	26%
K78421	1129849	75,102	58,422	26%
K78422	1129849	75,102	58,422	26%

All material made and melted in the U.S.

Thank you,

JOHN RATICA
MID-AMERICA STEEL CORPORATION

Figure B-18. 2-in. × ¼-in. (51-mm × 6-mm) Bent Steel Plate Material Certificate, Test No. NJPCB-5

ArcelorMittal

ArcelorMittal LaPlace
(HARRIMAN)
2404 S. ROANE STREET
HARRIMAN, TENNESSEE 37748
Telephone (865) 882-5100

MATERIAL CERTIFICATION REPORT

METAL TRADER INC, (TRIAD METAL)
1 Village Road
HORSHAM PA 19044
ETATS-UNIS

TRIAD METALS INTERNATIONAL
(WASSELL LAND)
3507 Grand Avenue
PITTSBURGH PA 15225
USA

Tested in Accordance
With: ASTM A6

Sales Order 148953-4
Product Flat bars
Heat NO. L99837
Cust.Mat.
Size 2" X1/2" X3.404

Date 09/09/2015
Cust 40008882
Grade A3652950
Length 20' 00"

PO: 81536
Ref. 80833851
Pieces 288
Weight 19607.04

CHEMICAL ANALYSIS	
C	0.13
Mn	0.88
P	0.007
S	0.018
Si	0.19
Cu	0.24
Ni	0.17
Cr	0.14
Mo	0.065
Cb	0.020
V	0
B	
Al	
Sn	0.012
N	
Ti	
Ci	
CE	

MECHANICAL PROPERTIES	TEST 1		TEST 2		TEST 3	
	IMPERIAL	METRIC	IMPERIAL	METRIC	IMPERIAL	METRIC
YIELD STRENGTH	52710 PSI	363 MPa	53770 PSI	371 MPa		
TENSILE STRENGTH	72220 PSI	498 MPa	74560 PSI	514 MPa		
ELONGATION	25 %	25 %	25 %	25 %		
GAUGE LENGTH	8 IN	203 mm	8 IN	203 mm		
BEND TEST DIAMETER						
BEND TEST RESULTS						
SPECIMEN AREA						
REDUCTION OF AREA						
IMPACT STRENGTH						

IMPACT STRENGTH	IMPERIAL	METRIC	INTERNAL CLEANLINESS		GRAIN SIZE	
AVERAGE			SEVERITY		HARDNESS	
TEST TEMP			FREQUENCY		GRAIN PRACTICE	
ORIENTATION			RATING		REDUCTION RATIO	

This heat makes the following grades: A36-08,A52950-05,G40.21-CSA50W,CSA44W,A70936-09a, ASME SA36-2010, A57250-07, A70950-10, AASHTO M270 Grade 36,AASHTO M270 Grade 50, AASHTO M270M Grade 345.

I hereby certify that the material test results presented here are from the reported heat and are correct. All tests were performed in accordance to the specification reported above. All steel is electric arc furnace melted (billets), manufactured, processed, tested in the U.S.A with satisfactory results. No weld repair was performed on this heat.

Notarized upon request:
Sworn to and subscribed before me on 9th day of September, 2015

Signed Keith D. Limburg
KEITH D. LIMBURG, QUALITY ASSURANCE MANAGER

Notary Public County

Direct any questions or necessary clarifications concerning this report to the Sales Department 1-800-535-7692(USA)

Figure B-19. ½-in. (13-mm) Thick Steel Plate Material Certificate, Test No. NJPCB-5

GERDAU

US-ML-CHARLOTTE
6601 LAKEVIEW ROAD
CHARLOTTE, NC 28269
USA

CERTIFIED MATERIAL TEST REPORT

Page 1/1

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE
TRIAD METALS 3507 GRAND AVE PITTSBURGH,PA 15225 USA	TRIAD METALS INTERNATIONAL MET 1 VILLAGE RD HORSHAM,PA 19044-3800 USA	GGMULTI	Flat / 1/2 X 2 1/4

LENGTH	WEIGHT	HEAT / BATCH
20'00"	4,979 LB	54144612/03

SALES ORDER	CUSTOMER MATERIAL N°
2819476/000010	

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
83055W	1321-0000034345	09/24/2015

SPECIFICATION / DATE or REVISION
A6-13A,A36-12, ASME SA36-13
ASTM A529-05(2009), A572-13A
ASTM A709-13A, AASHTO M270-12
CSA G40.20-13/G40.21-13

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	V %	Nb %	Sn %
0.17	0.71	0.011	0.033	0.20	0.47	0.14	0.17	0.030	0.015	0.002	0.013

MECHANICAL PROPERTIES

Elong. %	G/L Inch	UTS PSI	UTS MPa	YS PSI	YS MPa
29.40	8.000	74174	511	51422	355

GEOMETRIC CHARACTERISTICS

R:R
22.00

COMMENTS / NOTES

This grade meets the requirements for the following grades:
ASTM Grades: A36, A529-50; A572-50; A709-36, A709-50
CSA Grades: 44W; 50W
AASHTO Grades: M270-36; M270-50
ASME Grades: SA36

The above figures are certified chemical and physical test records as contained in the permanent records of company. We certify that these data are correct and in compliance with specified requirements. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

BHASKAR YALAMANCHILI
QUALITY DIRECTOR

JORDAN FOSTER
QUALITY ASSURANCE MGR.

Figure B-20. ½-in. (13-mm) Thick Steel Plate Material Certificate, Test No. NJPCB-5

DAYTON SUPERIOR

1107 Advantage Grout

Cement Based Grout

TECHNICAL DATA SHEET

DESCRIPTION

The 1107 Advantage Grout is a non-shrink, non-metallic, non-corrosive, cementitious grout that is designed to provide a controlled, positive expansion to ensure an excellent bearing area. The 1107 Advantage Grout can be mixed from a fluid to a dry pack consistency.

USE

Exterior grouting of structural column base plates, pump and machinery bases, anchoring bolts, dowels, bearing pads and keyway joints. It finds applications in paper mills, oil refineries, food plants, chemical plants, sewage and water treatment plants etc.

FEATURES

- Controlled, net positive expansion
- Non shrink
- Non metallic/non corrosive
- Pourable, pumpable or dry pack consistency
- Interior/exterior applications

PROPERTIES

Corps of Engineers Specification for non-shrink grout:

CRD-C 621 Grades A, B, C

ASTM C-1107 Grades A, B, C

ASTM C-827 - 1107 Advantage Grout yielded a controlled positive expansion

Expansion - ASTM C-1090:

1 day: 0-0.3

3 days: 0-0.3

14 days: 0-0.3

28 days: 0-0.3

Test Results

	@ 1 Day		@ 3 Days		@ 7 Days		@ 28 Days	
Fluidity	PSI	MPa	PSI	MPa	PSI	MPa	PSI	MPa
Dry-Pack	5000	34.5	7000	48.2	9000	62.0	10000	68.9
Flowable	2500	17.2	5000	34.5	6000	41.4	8000	55.1
Fluid	2000	13.8	4000	27.6	5000	34.5	7500	51.7

Note:
The data shown is typical for controlled laboratory conditions. Reasonable variation from these results can be expected due to interlaboratory precision and bias. When testing the field mixed material, other factors such as variations in mixing, water content, temperature and curing conditions should be considered.

Estimating Guide

Yield (Flowable Consistency):
0.43 cu. ft./50 lbs. (0.0122 cu. M/22.67 kg) bag
0.59 cu. ft./50 lbs. (0.017 cu. M/22.67 kg) bag extended with 25 lbs. (11.34 kg) of washed 3/8 in. (1cm) pea gravel

Packaging

PRODUCT CODE	PACKAGE	SIZE	
		lbs	kg
67435	Bag	50	22.67
67437	Supersack	3,000	1,360.78

STORAGE

Store in a cool, dry area free from direct sunlight. Shelf life of unopened bags, when stored in a dry facility, is 12 months. Excessive temperature differential and /or high humidity can shorten the shelf life expectancy.

APPLICATION

Surface Preparation:

Thoroughly clean all contact surfaces. Existing concrete should be strong and sound. Surface should be roughened to insure bond. Metal base plates should be clean and free of oil and other contaminants. Maintain contact areas between 45°F (7°C) and 90°F (32°C) before grouting and during curing period.

Thoroughly wet concrete contact area 24 hours prior to grouting, keep wet and remove all surface water just prior to placement. If 24 hours is not possible, then saturate with water for at least 4 hours. Seal forms to prevent water or grout loss. On the placement side, provide an angle in the form high enough to assist in grouting and to maintain head pressure on the grout during the entire grouting process. Forms should be at least 1 in. (2.5 cm) higher than the bottom of the base plate.

Water Requirements:

Desired Mix Water / 50 lbs. (22.67 kg) Bag
Dry Pack: 5 pints (2.4 L)
Flowable: 8 pints (3.8 L)
Fluid: 9 pints (4.2 L)

Mixing:

A mechanical mixer with rotating blades like a mortar mixer is best. Small quantities can be mixed with a drill and paddle. When mixing less than a full bag, always first agitate the bag thoroughly so that a representative sample is obtained.

Sec 16

Grouts

Figure B-21. Non-Shrink Grout Specifications, Test No. NJPCB-5

DAYTON SUPERIOR

1107 Advantage Grout

Cement Based Grout

TECHNICAL DATA SHEET

Place approximately 3/4 of the anticipated mix water into the mixer and add the grout mix, adding the minimum additional water necessary to achieve desired consistency.
Mix for a total of five minutes ensuring uniform consistency. For placements greater in depth than 3 in. (7.6 cm), up to 25 lbs. (11.34 kg) of washed 3/8 in. (1 cm) pea gravel must be added to each 50 lbs. (22.67 kg) bag of grout. The approximate working time (pot life) is 30 minutes but will vary somewhat with ambient conditions.

For hot weather conditions, greater than 85°F (29°C), mix with cold water approximately 40°F (4°C).
For cold weather conditions, less than 50°F (10°C), mix with warm water, approximately 90°F (29°C). For additional hot and cold weather applications, contact Dayton Superior.

Placement:
Grout should be placed preferably from one side using a grout box to avoid entrapping air. Grout should not be over-worked or over-watered causing segregation or bleeding. Vent holes should be provided where necessary.
When possible, grout bolt holes first. Placement and consolidation should be continuous for any one section of the grout. When nearby equipment causes vibration of the grout, such equipment should be shut down for a period of 24 hours. Forms may be removed when grout is completely self-supporting. For best results, grout should extend downward at a 45 degree angle from the lower edge of the steel base plates or similar structures.

Sec 16 Grouts

CLEAN UP

Use clean water. Hardened material will require mechanical removal methods.

CURING

Exposed grout surfaces must be cured. Dayton Superior recommends using a Dayton Superior curing compound, cure & seal or a wet cure for 3 days. Maintain the temperature of the grout and contact area at 45°F (7°C) to 90°F (32°C) for a minimum of 24 hours.

LIMITATIONS

FOR PROFESSIONAL USE ONLY

Do not re-temper after initial mixing
Do not add other
cements or additives
Setting time for the 1107 Advantage Grout will slow during cooler weather, less than 50°F (10°C) and speed up during hot weather, greater than 80°F (27°C)
Prepackaged material segregates while in the bag, thus when mixing less than a full bag it is recommended to first agitate the bag to assure it is blended prior to sampling.

PRECAUTIONS

READ SDS PRIOR TO USING PRODUCT

- Product contains Crystalline Silica and Portland Cement Avoid breathing dust Silica may cause serious lung problems
- Use with adequate ventilation
  n Wear protective clothing, gloves and eye protection (goggles, safety glasses and/or face shield)
- Keep out of the reach of children
- Do not take internally
- In case of ingestion, seek medical help immediately
- May cause skin irritation upon contact, especially prolonged or repeated. If skin contact occurs, wash immediately with soap and water and seek medical help as needed.
- If eye contact occurs, flush immediately with clean water and seek medical help as needed
- Dispose of waste material in accordanc

MANUFACTURER

Dayton Superior Corporation
1125 Byers Road
Miamisburg, OH 45342
Customer Service: 888-977-9600
Technical Services: 877-266-7732
Website: www.daytonsuperior.com

WARRANTY

Dayton Superior Corporation ("Dayton") warrants for 12 months from the date of manufacture or for the duration of the published product shelf life, whichever is less, that at the time of shipment by Dayton, the product is free of manufacturing defects and conforms to Dayton's product properties in force on the date of acceptance by Dayton of the order. Dayton shall only be liable under this warranty if the product has been applied, used, and stored in accordance with Dayton's instructions, especially surface preparation and installation, in force on the date of acceptance by Dayton of the order. The purchaser must examine the product when received and promptly notify Dayton in writing of any non-conformity before the product is used and no later than 30 days after such non-conformity is first discovered. If Dayton, in its sole discretion, determines that the product breached the above warranty, it will, in its sole discretion, replace the non-conforming product, refund the purchase price or issue a credit in the amount of the purchase price. This is the sole and exclusive remedy for breach of this warranty. Only a Dayton officer is authorized to modify this warranty. The information in this data sheet supersedes all other sales information received by the customer during the sales process. THE FOREGOING WARRANTY SHALL BE EXCLUSIVE AND IN LIEU OF ANY OTHER WARRANTIES, EXPRESS OR IMPLIED, INCLUDING WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE, AND ALL OTHER WARRANTIES OTHERWISE ARISING BY OPERATION OF LAW, COURSE OF DEALING, CUSTOM, TRADE OR OTHERWISE.

Visit www.daytonsuperior.com for the most up to date technical information
Page 2 of 3
File Date: 3/27/2015

Figure B-22. Non-Shrink Grout Specifications, Test No. NJPCB-5

benesch
engineers · scientists · planners

LINCOLN OFFICE
825 "M" Street, Suite 100
Lincoln, NE 68508
Phone: (402) 479-2200
Fax: (402) 479-2276

COMPRESSION TEST OF CYLINDRICAL CONCRETE SPECIMENS - 4x8

ASTM Designation: C 39

Client Name: Midwest Roadside Safety Facility **Date** 20-Jan-17
Project Name: New Jersey PCB
Placement Location: 4' Grout cylinder A

Mix Designation: Grout **Required Strength:** 1000

Laboratory Test Data

Laboratory Identification	Field Identification	Date Cast	Date Received	Date Tested	Days Cured in Field	Days Cured in Laboratory	Age of Test, Days	Length of Specimen, in.	Diameter of Specimen, in.	Cross-Sectional Area,sq.in.	Maximum Load, lbf	Compressive Strength, psi.	Required Strength, psi.	Type of Fracture	ASTM Practice for Capping Specimen
PCB- 2	A	1/19/2017	1/20/2017	1/20/2017	1	0	1	8	4.00	12.57	10,740	850	1,000	6	C 1231

1 cc: Shaun Tighe
Midwest Roadside Safety Facility

Remarks:

Concrete test specimens along with documentation and test data were submitted by Midwest Roadside Safety Facility.

Test results presented relate only to the concrete specimens as received from Midwest Roadside Safety

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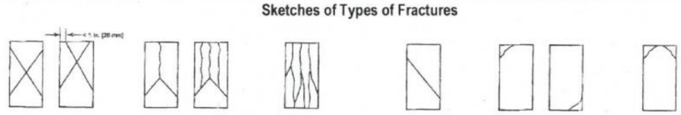
Report Number 2147369000
Page 1

Sketches of Types of Fractures



Type 1 — Reasonably well-formed cones on both ends, less than 1 in. [25 mm] of cracking through caps

Type 2 — Well-formed cone on one end, vertical cracks running through caps, no well-defined cone on other end

Type 3 — Columnar vertical cracking through both ends, no well-formed cones

Type 4 — Diagonal fracture with no cracking through ends; tap with hammer to distinguish from Type 1

Type 5 — Side fractures at top or bottom (occur commonly with unbonded caps)

Type 6 — Similar to Type 5 but end of cylinder is pointed

ALFRED BENESCH & COMPANY
CONSTRUCTION MATERIALS LABORATORY

By ____________
Brant Wells, Field/Lab Operations Manager

Figure B-23. Non-shrink Grout Compressive Test Certificate, Test No. NJPCB-5

LINCOLN OFFICE
825 "M" Street, Suite 100
Lincoln, NE 68508
Phone: (402) 479-2200
Fax: (402) 479-2276

benesch
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COMPRESSION TEST OF CYLINDRICAL CONCRETE SPECIMENS - 4x8

ASTM Designation: C 39

Client Name: Midwest Roadside Safety Facility
Project Name: New Jersey PCB
Placement Location: New Jersey PCB-5 Cylinder A

Date 27-Jan-17

Mix Designation: grout

Required Strength: 1000

Laboratory Test Data

Laboratory Identification	Field Identification	Date Cast	Date Received	Date Tested	Days Cured in Field	Days Cured in Laboratory	Age of Test, Days	Length of Specimen, in.	Diameter of Specimen, in.	Cross-Sectional Area,sq.in.	Maximum Load, lbf	Compressive Strength, psi.	Required Strength, psi.	Type of Fracture	ASTM Practice for Capping Specimen
PCB- 3	A	1/24/2017	1/27/2017	1/27/2017	3	0	3	8	4.01	12.63	40,563	3,210	1,000	5	C 1231

1 cc: Shaun Tighe
Midwest Roadside Safety Facility

Remarks:

Concrete test specimens along with documentation and test data were submitted by Midwest Roadside Safety Facility.

Test results presented relate only to the concrete specimens as received from Midwest Roadside Safety

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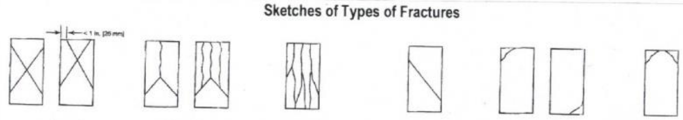
Report Number 2147369001
Page 1

Sketches of Types of Fractures



Type 1: Reasonably well-formed cones on both ends, less than 1 in. [25 mm] of cracking through caps

Type 2: Well-formed cone on one end, vertical cracks running through caps, no well-defined cone on other end

Type 3: Columnar vertical cracking through both ends, no well-formed cones

Type 4: Diagonal fracture with no cracking through ends; tap with hammer to distinguish from Type 1

Type 5: Side fractures at top or bottom (occur commonly with unbonded caps)

Type 6: Similar to Type 5 but end of cylinder is pointed

ALFRED BENESCH & COMPANY
CONSTRUCTION MATERIALS LABORATORY

By ____
Brant Wells, Field/Lab Operations Manager

Figure B-24. Non-shrink Grout Compressive Test Certificate, Test No. NJPCB-5

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LINCOLN OFFICE
825 "M" Street, Suite 100
Lincoln, NE 68508
Phone: (402) 479-2200
Fax: (402) 479-2276

COMPRESSION TEST OF CYLINDRICAL CONCRETE SPECIMENS - 4x8

ASTM Designation: C 39

Client Name: Midwest Roadside Safety Facility
Project Name: New Jersey PCB
Placement Location: New Jersey PCB-5 Cylinder B

Date 27-Jan-17

Mix Designation: grout

Required Strength: 1000

Laboratory Test Data

Laboratory Identification	Field Identification	Date Cast	Date Received	Date Tested	Days Cured in Field	Days Cured in Laboratory	Age of Test, Days	Length of Specimen, in.	Diameter of Specimen, in.	Cross-Sectional Area, sq.in.	Maximum Load, lbf	Compressive Strength, psi.	Required Strength, psi.	Type of Fracture	ASTM Practice for Capping Specimen
PCB- 4	B	1/24/2017	1/27/2017	1/27/2017	3	0	3	8	4.00	12.57	37,983	3,020	1,000	6	C 1231

1 cc: Shaun Tighe
Midwest Roadside Safety Facility

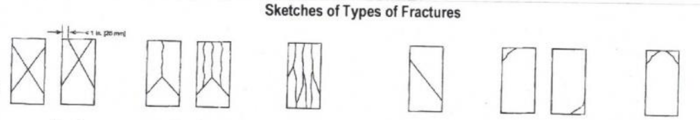
Remarks:

All concrete test data in this report was produced by Benesch personnel using ASTM Standard Methods and Practices unless otherwise noted.

Test results presented relate only to the concrete sampled by Benesch personnel as referenced above.

Report Number 2147369002
Page 1

Sketches of Types of Fractures



Type 1 — Reasonably well-formed cones on both ends, less than 1 in. [25 mm] of cracking through caps

Type 2 — Well-formed cone on one end, vertical cracks running through caps, no well-defined cone on other end

Type 3 — Columnar vertical cracking through both ends, no well-formed cones

Type 4 — Diagonal fracture with no cracking through ends; tap with hammer to distinguish from Type 1

Type 5 — Side fractures at top or bottom (occur commonly with unbonded caps)

Type 6 — Similar to Type 5 but end of cylinder is pointed

ALFRED BENESCH & COMPANY
CONSTRUCTION MATERIALS LABORATORY

By [signature]
Brant Wells, Field/Lab Operations Manager

Figure B-25. Non-shrink Grout Compressive Test Certificate, Test No. NJPCB-5

IPSCO

CERTIFICATE OF TESTING
IPSCO TUBULARS INC

Page 1

Certificate Number: 293582-1

Bill of Lading: 395579

Wednesday, August 17, 2016, 11:35:22 AM

Size: 6.000 X 6.000 in	Gage: 0.188 in	Grade: A500B	Mill Order No: 76967-01	Customer PO: P60811KH011

Specification: ASTM A500-01
PRODUCT MEETS SPECIFICATION REQUIREMENTS
FOR GRADES B AND C.

Customer: STATE STEEL SUPPLY CO.

Pieces: 6 Length: 48.00 (ft)

Heat	Product ID	Test Type			Orientation				Width (in)		YS (psi)		TS (psi)		Elong%(2 in)		Y/T	
		Wgt (%)	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Sn	Al	V	Cb	Ti	B	CEQ
B38461	G-866E D100886-	HEAT QUALIFIER			PIPE LPA				1.500		54700		66300		41.0		0.83	
		Heat	0.23	0.46	0.010	0.001	0.08	0.01	0.01	0.03	0.005	0.001	0.041	0.002	0.001	0.003	0.0000	0.32

P60811KH01101

B38461

TPA - Transverse Pipe Axis
180° of Weld
LPA - Longitudinal Pipe Axis
J° of Weld
TWA - Transverse Weld Axis
FST - Full Section Testing
FBN - Full Body Normalized
Q&T - Quenched and Tempered
SR - Stress Relieved
form CRTR3001

Melted and Manufactured in the USA
EN 10204:2004 TYPE 3.1 CERT

We certify that the product described above has been manufactured, s... inspected, and tested in accordance to the referenced specification. The product has been found to be in compliance with all requirements.

Andrew Simon
QA Coordinator

Wednesday, August 17, 2016, 11:35:36 AM

MILL ADDRESS - 1201-R ST., GENEVA, NE 68361 | PHONE: (402) 759-4401

Figure B-26. Box Beam Stiffener Material Certificate, Test No. NJPCB-5

R#17-280
NewJerseyPCB-5
Tubes and Plates
Nov 2016 SMT

NLMK INDIANA
Member of NLMK Group

NLMK INDIANA
6500 SOUTH BOUNDARY ROAD
PORTAGE, IN 46368
PHONE: 219.787.8200

10/19/2015 14:57
CSTM8105
Page 3 of 3

CERTIFICATE OF TEST FOR COIL 5138785 HEAT# T3079

SOLD TO: STATE STEEL SUPPLY
208 COURT STREET
PO BOX 3224
SIOUX CITY, IA 51102

SHIP TO: STATE STEEL SUPPLY
208 COURT STREET
SIOUX CITY, IA 51102

ORDER SPECIFICATIONS

CUSTOMER PO: P50820BL901-2
RESULTS FOR COIL: 5138785
PRODUCT TYPE: HR
PRODUCT CATEGORY: A1018 G36 T2 .050SI
ORDERED GRADE: 1017
ORDERED GAUGE: 0.4950 MIN
GAUGE TOL: +0.0220/-0.0000
ORDERED WIDTH: 60.0000 MIN
WIDTH TOL: +1.5000/-0.0000

ORDER: 3029467
EDGE: MILL
FINISH: PICKLE
HARDNESS: NA
HARDNESS RANGE: NA
YIELD: 36000
TENSILE: 58000/80000
ELONGATION: 23%
BEND:

ITEM: 41223469
INDUSTRY SPEC: A1018 SS GR36 TY2/CONV TO A36/CONV TO SA-36
CUSTOMER SPEC: NA
CUSTOMER PART #:
CERT #: 14
CUSTOMER NOTE:

JOB #	COIL #	SIZE	WGT	YIELD	TENSILE	ELONGATION
3029467-01	5138472	0.4950 x 60.0000	46340	52,500	72,400	33.0

HEAT# T3079 (Country of Origin: MELT & MFG IN USA)
C: .18 - MN: .34 - P: .012 - S: .005 - SI: .041 - AL: .037 - CU: .14 - NI: .06 - CR: .10 - MO: .02 - SN: .035 - TI: .002 - V: .001 - NB: .003 - N: .007 - B: .0000 - CA: .0017 - CE: * - ZR: * - AS: * - SB: .001

JOB #	COIL #	SIZE	WGT	YIELD	TENSILE	ELONGATION
3029467-02	5138785	0.4950 x 60.0000	46270	57,400	76,600	27.0

HEAT# T3079 (Country of Origin: MELT & MFG IN USA)
C: .18 - MN: .34 - P: .012 - S: .005 - SI: .041 - AL: .037 - CU: .14 - NI: .06 - CR: .10 - MO: .02 - SN: .035 - TI: .002 - V: .001 - NB: .003 - N: .007 - B: .0000 - CA: .0017 - CE: * - ZR: * - AS: * - SB: .001

P60204KK09101

T3079

Manufactured in the United States of America - 'BUY AMERICAN' Compliant.

Elements with a reported value of "*" were undetected, and thus are less than .001%.
NLMK INDIANA certifies that the material listed herein has been tested in accordance with the methods prescribed in the governing specifications. Based upon the results of such testing, the material conforms to the specifications. All testing has been performed using the current revision of the testing specifications.

Robert M Chace
Robert M Chace
Applications Engineer

Figure B-27. Box Beam Steel Plates Material Certificate, Test No. NJPCB-5

Portland Bolt & MANUFACTURING COMPANY

Phone: 800-547-6758 | Fax: 503-227-4634
3441 NW Guam Street, Portland, OR 97210
Web: www.portlandbolt.com | Email: sales@portlandbolt.com

CERTIFICATE OF CONFORMANCE

For: CASH SALE
PB Invoice#: 94836
Cust PO#: MIDWEST ROADSIDE
Date: 12/01/2016
Shipped: 12/05/2016

We certify that the following items were manufactured and tested in accordance with the chemical, mechanical, dimensional and thread fit requirements of the specifications referenced.

Description: 3/4 X 17 BLK ASTM A307A ROUND HEAD BOLT

Heat#: 529615 **Base Steel:** A36 **Diam:** 3/4

Source: CASCADE STEEL RLG MILL **Proof Load:** 0

C :	.180	**Mn:**	.670	**P :**	.018	**Hardness:**	0				
S :	.026	**Si:**	.230	**Ni:**	.090	**Tensile:**	71,000 PSI	**RA:**	53.00%		
Cr:	.160	**Mo:**	.030	**Cu:**	.220	**Yield:**	47,700 PSI	**Elon:**	25.00%		
Pb:	.000	**V :**	.003	**Cb:**	.000	**Sample Length:**	8 INCH				
N :	.000			**CE:**	.3167	**Charpy:**		**CVN Temp:**			

Nuts:
ASTM A563DH HVY HX

By: Certification Department Quality Assurance
Dane McKinnon

NJPCB-5 Dome Head Bolts and Nuts
R#17-289 December 2016

Figure B-28. Box Beam Mounting Bolts Material Certificate, Test No. NJPCB-5

King Socket Screw Co.,Ltd

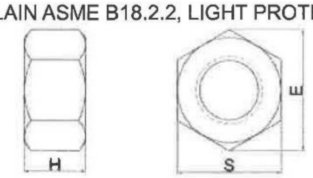
NO. 231 Jixing Road Wuyuan Industrial Park Haiyan, Zhejiang China
TEL：+86-573-8605-9549 FAX：+86-573-8605-9349
Company Web：http://www.lwfasteners.com.tw
Company E-mail：king-lin@lwfasteners.com.tw

ISO 9001 2008 FS 503874 LWFC ESTABLISHED IN 1982

REPORT OF TESTING

COUNTRY OF ORIGIN : CHINA

CUSTOMERS : BRIGHTON-BEST INTERNATIONAL (TAIWAN) INC. CLOSE DATE : AUG.05,2016
CUSTOMERS ORDER NO.：U34726
SIZE：3/4 – 10
DESCRIPTION：A563 GRADE DH, HEAVY HEX NUT PLAIN ASME B18.2.2, LIGHT PROTECTIVE OIL
INV. NO.：KS160804-TB-LAC
PART NO.：228074
LOT NO.：U34726-228074
LOT SIZE： 4,750 PCS
SAMPLE SIZE：ASME B18.18-11
MANUFACTURER：KH11



DIMENSIONS OF SPEC：PER ASME B18.2.2-2010 (MEASUREMENT BY INCHES)

INSPECTION ITEMS	STANDARD	RESULT	AC.	RE.
VISUAL APPEARANCE	ASTM F812/F812M	OK	22	0
THREAD GO GAGE	2B ASME B1.1	OK	15	0
THREAD NO GO GAGE	2B ASME B1.1	OK	15	0
WIDTH ACROSS FLATS (S)	1.212 – 1.250	1.219 – 1.244	4	0
WIDTH ACROSS CORNERS (E)	1.382 – 1.443	1.407 – 1.435	4	0
HEIGHT (H)	0.710 – 0.758	0.715 – 0.726	4	0
HEAD MAKRED	JS+DH	OK	22	0

MECHANICAL PROPERTIES：PER ASTM A563-2007a(R2014)

INSPECTION ITEMS	TEST METHOD	STANDARD	RESULT	AC.	RE.
HARDNESS	ASTM F606	HRC 24 – 38	HRC 24 – 28	4	0
PROOF LOAD	ASTM F606	MIN 175 KSI	175 – 176 KSI	3	0

CHEMICAL ANALYSIS (%)： SPECIFICATION : SWRCH35K

HEAT NO.& DIA (mm)		C $X10^2$	Si $X10^2$	Mn $X10^2$	P $X10^3$	S $X10^3$	N $X10^4$	Cr $X10^2$	Ni $X10^2$	Cu $X10^2$
G420007618	24.00 mm	36	16	73	15	3	75	2	2	4

STEEL MAKER.： JIANGSU SHAGANG GROUP CO.,LTD
CERTIFICATE NO.：M832188637X4CA005600171

REMARKS：
- ✧ THIS REPORT MUST NOT BE REPRODUCED EXCEPT IN FULL AND THE TEST REPORT RELATES ONLY TO THE ITEM TESTED.
- ✧ THE REPORT IS ISSUED ACCORDING TO EN10204, 3.1
- ✧ THE QMS IS APPROVED TO ISO 9001 BY BSI . NO.: FS 503874 .
- ✧ Tr: TRACE ELEMENT WITH ITS CONTENT CONFORMING TO THE SPECIFICATION.

YANJUAN CHEN	Maurice Yang	King Lin
INSPECTOR	VERIFICATION	AUTHORIZATION

28329-3

Figure B-29. Box Beam Mounting Nuts Material Certificate, Test No. NJPCB-5

Appendix C. Concrete Tarmac Strength

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LINCOLN OFFICE
825 J Street
Lincoln, NE 68508
402/479-2200

COMPRESSION TEST OF Cylindrical CONCRETE SPECIMENS
ASTM Designation: C39-03

Client:	UNL			Date:	December 10, 2010	
Project:	MwRSF					
Placement Location:	WI - East 1, 2, 3					
Mix Type:	Class:			Mix No.:		
Type of Forms			Cement Factor, Sks/Yd		na	
			Water-Cement Ratio		na	
Admixture Quantity	na		Slump Inches		na	
Admixture Type	na		Unit Wt, lbs/cu. Ft.		na	
Admixture Quantity	na		Air Content, %		na	
Average Field Temperature	na		Batch Volume, Cu. Yds.		na	
Temperature of Concrete F	na		Ticket No.		na	
Identification Laboratory	East 1	East 2	East 3			
Date Cast						
Date Received in Laboratory	11/30/2010	11/30/2010	11/30/2010			
Date Tested						
Days Cured in Field						
Days Cured in Laboratory						
Age of Test, Days						
Length, in.	7.78	7.81	7.75			
Average Width (1), in.	3.72	3.72	3.72			
Cross-Sectional Area, sq. in.	10.874	10.869	10.874			
Maximum Load, lbf	71,030	76,470	73,310			
Compressive Stength, psi	6,530	7,040	6,740			
Length/Diameter Ratio	2.091	2.099	2.083			
Correction						
Corrected Compressive Strength,psi	0	0	0			
Type of Fracture	4	4	4			
Required Strength,psi						

Remarks:

All concrete break data in this report was produced by Benesch personnel using ASTM Standard Methods and Practices unless otherwise noted.

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ALFRED BENESCH & COMPANY
CONSTRUCTION MATERIALS LABORATORY

By: Raymond E. Delka
Raymond E. Delka, Manager

Figure C-1. Concrete Tarmac Strength Test, Test No. NJPCB-5

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LINCOLN OFFICE
825 J Street
Lincoln, NE 68508
402/479-2200

COMPRESSION TEST OF Cylindrical CONCRETE SPECIMENS
ASTM Designation: C39-03

Client:	UNL	Date:	December 13, 2010
Project:	MwRSF		
Placement Location:	WI - Epoxy West 4 &5		
Mix Type:	Class:	Mix No.:	
Type of Forms		Cement Factor, Sks/Yd	na
		Water-Cement Ratio	na
Admixture Quantity	na	Slump Inches	na
Admixture Type	na	Unit Wt, lbs/cu. Ft.	na
Admixture Quantity	na	Air Content, %	na
Average Field Temperature	na	Batch Volume, Cu. Yds.	na
Temperature of Concrete F	na	Ticket No.	na

Identification Laboratory	4	5				
Date Cast						
Date Received in Laboratory	12/13/2010	12/13/2010				
Date Tested						
Days Cured in Field						
Days Cured in Laboratory						
Age of Test, Days	na	na				
Length, in.	8.05	8.06				
Average Width (1), in.	3.91	3.90				
Cross-Sectional Area, sq. in.	11.977	11.952				
Maximum Load, lbf	71,500	71,630				
Compressive Stength, psi	5,970	5,990				
Length/Diameter Ratio	2.061	2.065				
Correction						
Corrected Compressive Strength,psi	0	0				
Type of Fracture	3	3				
Required Strength,psi						

Remarks:

All concrete break data in this report was produced by Benesch personnel using ASTM Standard Methods and Practices unless otherwise noted.

ALFRED BENESCH & COMPANY
CONSTRUCTION MATERIALS LABORATORY

By: Raymond E. Delka, Manager

Figure C-2. Concrete Tarmac Strength Test, Test No. NJPCB-5

Appendix D. Vehicle Center of Gravity Determination

Date: 1/31/2017 **Test Name:** NJPCB-5 **VIN:** 1D3HB18P19S779289
Year: 2009 **Make:** Dodge **Model:** Ram

Vehicle CG Determination

VEHICLE	Equipment	Weight (lb.)	Vertical CG (in.)	Vertical M (lb.-in.)
+	Unballasted Truck (Curb)	5084	28 4/5	146482.75
+	Hub	19	15 3/8	292.125
+	Brake activation cylinder & frame	7	28 1/2	199.5
+	Pneumatic tank (Nitrogen)	27	26 1/2	715.5
+	Strobe/Brake Battery	5	25 1/2	127.5
+	Brake Receiver/Wires	5	52	260
+	CG Plate including DAS	42	30	1260
-	Battery	-48	39	-1872
-	Oil	-7	27	-189
-	Interior	-96	28	-2688
-	Fuel	-174	17 1/2	-3045
-	Coolant	-15	31	-465
-	Washer fluid	-1	35	-35
+	Water Ballast (In Fuel Tank)	124	17 1/2	2170
+	Onboard Supplemental Battery	12	25	300
+	DTS TDAS	17	27	459
				143972.38

Note: (+) is added equipment to vehicle, (-) is removed equipment from vehicle

Estimated Total Weight (lb.) 5001
Vertical CG Location (in.) 28.7887

Vehicle Dimensions for C.G. Calculations

Wheel Base: 139 7/8 in. Front Track Width: 68 1/4 in.
Rear Track Width: 68 3/8 in.

Center of Gravity	2270P MASH Targets	Test Inertial	Difference
Test Inertial Weight (lb.)	5000 ± 110	5001	1.0
Longitudinal CG (in.)	63 ± 4	61.588632	-1.41137
Lateral CG (in.)	NA	0.0068299	NA
Vertical CG (in.)	28 or greater	28.79	0.78872

Note: Long. CG is measured from front axle of test vehicle
Note: Lateral CG measured from centerline - positive to vehicle right (passenger) side

CURB WEIGHT (lb.)

	Left	Right
Front	1480	1379
Rear	1118	1107

FRONT 2859 lb.
REAR 2225 lb.
TOTAL 5084 lb.

TEST INERTIAL WEIGHT (lb.)

	Left	Right
Front	1403	1396
Rear	1097	1105

FRONT 2799 lb.
REAR 2202 lb.
TOTAL 5001 lb.

Figure D-1. Vehicle Mass Distribution, Test No. NJPCB-5

Appendix E. Vehicle Deformation Records

Date: 2/27/2018 Test Name: NJPCB-5 VIN: 1D3HB18P19S779289
Year: 2009 Make: Dodge Model: Ram

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 1

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)	Crush (in.)
1	28.635	-28.450	3.080	27.488	-28.040	3.841	-1.147	0.411	0.761	1.437	1.377
2	29.968	-25.247	1.730	28.668	-24.553	2.912	-1.300	0.694	1.182	1.889	1.757
3	30.700	-19.757	0.010	29.989	-19.340	1.221	-0.711	0.416	1.210	1.464	1.404
4	28.670	-12.982	0.286	28.669	-12.654	0.287	-0.001	0.328	0.002	0.328	0.002
5	26.212	-29.480	-0.811	25.874	-28.989	-0.456	-0.338	0.491	0.355	0.693	0.490
6	26.300	-25.081	-1.341	25.954	-24.671	-0.786	-0.346	0.410	0.555	0.772	0.654
7	26.230	-18.867	-1.986	25.740	-18.400	-1.173	-0.490	0.467	0.813	1.058	0.949
8	26.040	-13.239	-2.575	26.070	-12.934	-2.484	0.030	0.305	0.091	0.319	0.096
9	22.573	-29.739	-2.924	22.407	-29.382	-2.760	-0.167	0.357	0.164	0.427	0.164
10	22.541	-25.030	-3.406	22.274	-24.733	-3.034	-0.266	0.297	0.372	0.546	0.372
11	22.474	-19.101	-4.061	22.278	-18.758	-3.776	-0.196	0.343	0.284	0.486	0.284
12	22.467	-13.619	-4.614	22.348	-13.276	-4.563	-0.120	0.342	0.050	0.366	0.050
13	18.473	-29.761	-4.215	18.500	-29.342	-4.285	0.027	0.419	-0.070	0.426	-0.070
14	18.481	-25.117	-4.593	18.464	-24.837	-4.597	-0.017	0.280	-0.005	0.281	-0.005
15	18.574	-19.386	-5.188	18.697	-19.134	-5.200	0.123	0.251	-0.012	0.280	-0.012
16	18.626	-13.730	-5.801	18.612	-13.371	-5.833	-0.015	0.358	-0.032	0.360	-0.032
17	15.223	-29.612	-4.117	15.251	-29.289	-4.329	0.029	0.323	-0.213	0.388	-0.213
18	15.198	-25.026	-4.522	15.212	-24.711	-4.618	0.014	0.314	-0.096	0.329	-0.096
19	14.912	-19.075	-5.117	14.974	-18.720	-5.141	0.063	0.355	-0.024	0.361	-0.024
20	14.893	-13.342	-5.731	14.861	-13.036	-5.762	-0.031	0.306	-0.031	0.310	-0.031
21	10.329	-29.253	-3.765	10.346	-28.936	-4.019	0.017	0.318	-0.253	0.407	-0.253
22	10.209	-24.413	-4.180	10.253	-24.067	-4.377	0.044	0.346	-0.198	0.401	-0.198
23	10.103	-18.124	-4.821	10.117	-17.843	-4.855	0.014	0.281	-0.034	0.284	-0.034
24	10.146	-13.375	-5.337	10.149	-13.058	-5.374	0.003	0.317	-0.038	0.319	-0.038
25	0.171	-26.853	0.123	0.241	-26.561	0.142	0.070	0.292	0.019	0.301	0.019
26	0.196	-21.762	-0.389	0.264	-21.444	-0.387	0.068	0.318	0.001	0.325	0.001
27	0.108	-16.361	-0.964	0.112	-16.032	-0.978	0.004	0.328	-0.014	0.329	-0.014
28	0.030	-12.358	-1.406	0.101	-12.083	-1.422	0.071	0.275	-0.016	0.284	-0.016

Note: Crush column is deformation perpendicular to the plane area of interest

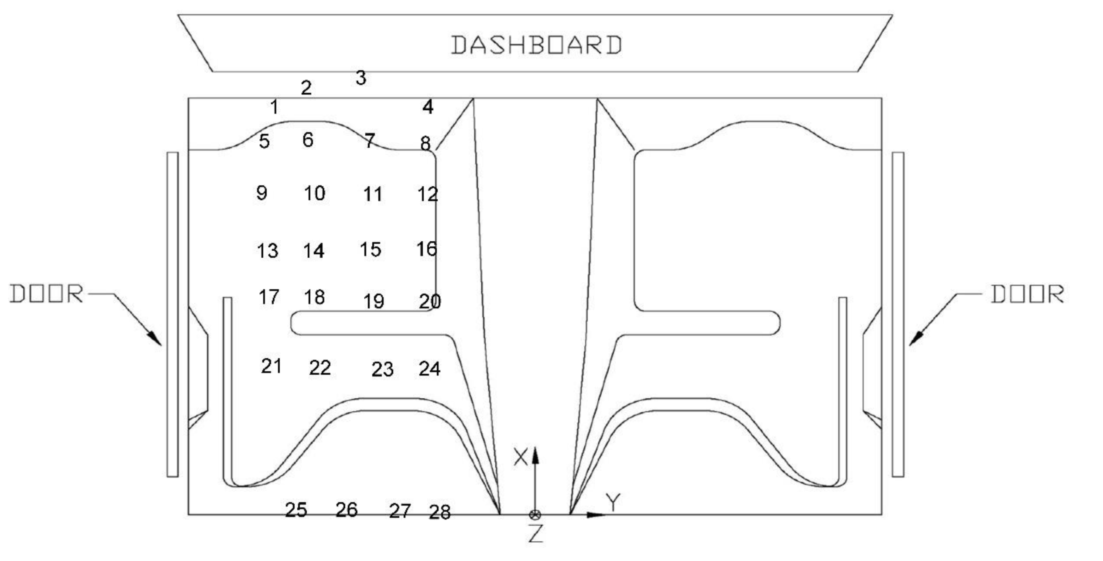


Figure E-1. Floor Pan Deformation Data – Set 1, Test No. NJPCB-5

Date: 2/27/2018 Test Name: NJPCB-5 VIN: 1D3HB18P19S779289
Year: 2009 Make: Dodge Model: Ram

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 2

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)	Crush (in.)
1	50.472	-29.123	2.450	49.198	-29.137	3.087	-1.274	-0.015	0.637	1.425	1.425
2	51.934	-25.861	1.534	50.513	-25.546	2.515	-1.421	0.316	0.981	1.756	1.727
3	52.773	-20.218	0.289	51.935	-20.251	1.446	-0.837	-0.033	1.157	1.429	1.429
4	50.868	-13.379	1.170	50.865	-13.484	1.224	-0.003	-0.105	0.054	0.118	0.054
5	48.139	-29.646	-1.625	47.679	-29.599	-1.247	-0.460	0.047	0.378	0.597	0.595
6	48.332	-25.189	-1.698	47.875	-25.207	-1.198	-0.457	-0.018	0.500	0.678	0.678
7	48.412	-18.923	-1.731	47.831	-18.936	-0.939	-0.581	-0.013	0.792	0.982	0.982
8	48.333	-13.363	-1.791	48.329	-13.405	-1.664	-0.003	-0.042	0.127	0.134	0.127
9	44.572	-29.658	-3.833	44.348	-29.562	-3.709	-0.223	0.096	0.124	0.273	0.124
10	44.656	-25.005	-3.843	44.339	-24.886	-3.510	-0.317	0.120	0.333	0.475	0.333
11	44.710	-18.939	-3.925	44.425	-18.910	-3.680	-0.285	0.029	0.245	0.377	0.245
12	44.776	-13.408	-3.968	44.647	-13.445	-3.888	-0.129	-0.037	0.080	0.156	0.080
13	40.574	-29.465	-5.233	40.482	-29.365	-5.373	-0.092	0.100	-0.141	0.196	-0.141
14	40.566	-24.798	-5.152	40.556	-24.817	-5.217	-0.010	-0.019	-0.066	0.069	-0.066
15	40.901	-19.096	-5.178	40.843	-19.032	-5.228	-0.059	0.064	-0.050	0.100	-0.050
16	41.054	-13.340	-5.233	41.014	-13.353	-5.257	-0.040	-0.012	-0.024	0.049	-0.024
17	37.266	-29.246	-5.213	37.203	-29.190	-5.514	-0.062	0.056	-0.301	0.313	-0.301
18	37.363	-24.662	-5.166	37.284	-24.634	-5.325	-0.080	0.027	-0.159	0.180	-0.159
19	37.284	-18.634	-5.185	37.201	-18.601	-5.229	-0.083	0.033	-0.044	0.099	-0.044
20	37.252	-12.889	-5.232	37.241	-12.848	-5.262	-0.011	0.041	-0.030	0.052	-0.030
21	32.361	-28.861	-4.971	32.266	-28.826	-5.312	-0.095	0.035	-0.342	0.356	-0.342
22	32.365	-23.929	-4.908	32.335	-23.881	-5.166	-0.030	0.047	-0.258	0.264	-0.258
23	32.374	-17.631	-4.933	32.385	-17.572	-5.001	0.011	0.059	-0.067	0.090	-0.067
24	32.526	-12.829	-4.978	32.525	-12.799	-5.003	-0.001	0.031	-0.025	0.040	-0.025
25	22.140	-26.579	-1.155	22.175	-26.553	-1.231	0.035	0.026	-0.076	0.088	-0.076
26	22.305	-21.526	-1.164	22.315	-21.410	-1.227	0.011	0.116	-0.063	0.132	-0.063
27	22.362	-16.022	-1.208	22.300	-15.958	-1.257	-0.063	0.065	-0.049	0.102	-0.049
28	22.391	-12.024	-1.255	22.351	-12.026	-1.290	-0.041	-0.002	-0.035	0.054	-0.035

Note: Crush column is deformation perpendicular to the plane area of interest

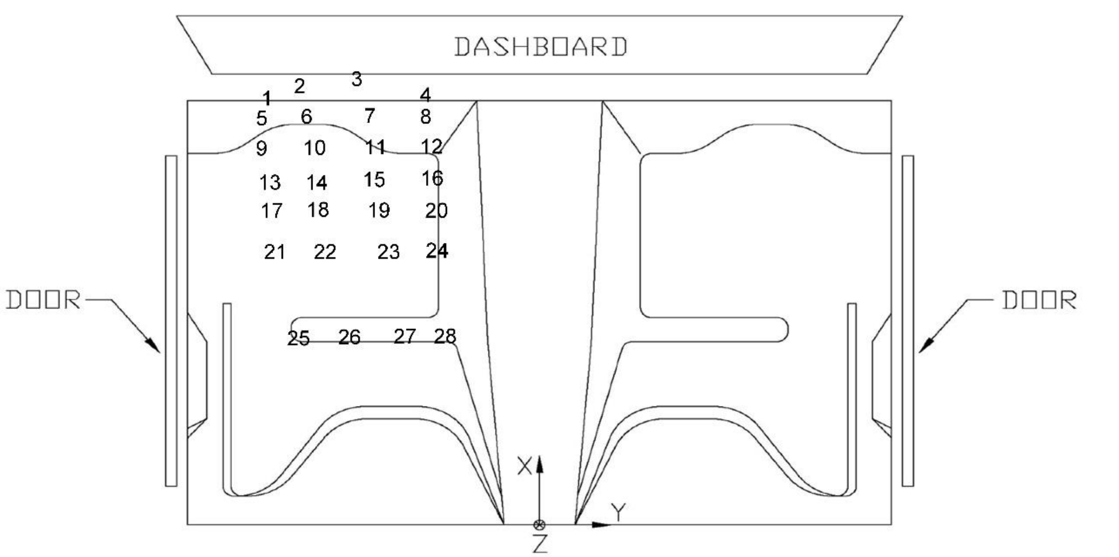


Figure E-2. Floor Pan Deformation Data – Set 2, Test No. NJPCB-5

Date: 2/27/2018 Test Name: NJPCB-5 VIN: 1D3HB18P19S779289
Year: 2009 Make: Dodge Model: Ram

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 1

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)	Crush (in.)
DASH	1	15.620	-27.892	26.717	15.481	-27.667	26.871	-0.139	0.225	0.154	0.306	0.306
	2	13.552	-15.681	29.304	13.402	-15.538	29.383	-0.151	0.143	0.079	0.222	0.222
	3	12.109	2.556	24.670	12.041	2.664	24.728	-0.068	0.109	0.058	0.140	0.140
	4	12.745	-28.166	15.799	12.682	-27.967	15.947	-0.063	0.199	0.148	0.256	0.256
	5	10.412	-17.488	15.195	10.345	-17.398	15.289	-0.067	0.090	0.094	0.146	0.146
	6	9.209	1.194	12.976	9.135	1.450	12.929	-0.074	0.255	-0.048	0.270	0.270
SIDE PANEL	7	21.155	-31.936	6.429	21.128	-31.621	6.662	-0.027	0.315	0.232	0.392	0.315
	8	24.607	-32.083	5.744	24.549	-31.766	5.964	-0.058	0.317	0.220	0.390	0.317
	9	22.800	-32.277	2.674	22.819	-31.953	2.833	0.019	0.324	0.159	0.362	0.324
IMPACT SIDE DOOR	10	-13.411	-31.955	25.632	-13.502	-32.558	25.768	-0.091	-0.602	0.136	0.624	-0.602
	11	-2.482	-31.787	25.082	-2.590	-32.154	25.322	-0.108	-0.367	0.241	0.452	-0.367
	12	10.509	-31.569	24.308	10.353	-31.685	24.522	-0.156	-0.116	0.214	0.290	-0.116
	13	-10.945	-33.954	12.914	-10.940	-34.106	13.080	0.006	-0.152	0.166	0.225	-0.152
	14	0.897	-34.770	11.849	0.781	-34.758	11.954	-0.116	0.012	0.105	0.157	0.012
	15	11.970	-33.152	10.879	11.856	-32.925	11.055	-0.115	0.227	0.176	0.309	0.227
ROOF	16	4.320	-21.853	42.983	4.231	-21.641	43.097	-0.089	0.212	0.114	0.257	0.114
	17	6.344	-15.711	42.605	6.232	-15.441	42.735	-0.111	0.270	0.130	0.320	0.130
	18	7.692	-10.107	42.095	7.504	-9.880	42.258	-0.188	0.227	0.163	0.337	0.163
	19	8.337	-3.591	41.644	8.224	-3.418	41.759	-0.112	0.173	0.115	0.236	0.115
	20	8.784	3.992	40.830	8.647	4.197	40.958	-0.137	0.206	0.128	0.279	0.128
	21	-2.043	-19.282	46.022	-2.170	-19.127	46.137	-0.127	0.154	0.115	0.231	0.115
	22	-0.991	-14.094	45.809	-1.151	-13.858	45.929	-0.160	0.237	0.120	0.310	0.120
	23	-0.436	-8.955	45.518	-0.571	-8.746	45.630	-0.136	0.208	0.112	0.273	0.112
	24	0.262	-3.139	45.023	0.084	-2.920	45.138	-0.178	0.219	0.115	0.305	0.115
	25	0.263	3.681	44.420	0.168	3.901	44.509	-0.095	0.220	0.090	0.256	0.090
	26	-6.658	-18.757	46.763	-6.823	-18.561	46.877	-0.165	0.196	0.114	0.281	0.114
	27	-6.061	-13.833	46.603	-6.127	-13.643	46.702	-0.066	0.190	0.099	0.224	0.099
	28	-5.288	-8.715	46.277	-5.484	-8.538	46.392	-0.196	0.177	0.115	0.288	0.115
	29	-4.004	-2.994	45.727	-4.066	-2.825	45.823	-0.061	0.169	0.096	0.204	0.096
	30	-3.267	3.419	45.047	-3.461	3.761	45.141	-0.194	0.342	0.093	0.404	0.093
A PILLAR	31	4.740	-23.474	41.642	4.647	-23.263	41.818	-0.093	0.211	0.176	0.290	0.211
	32	8.585	-24.583	39.607	8.508	-24.383	39.748	-0.078	0.200	0.140	0.256	0.200
	33	15.012	-26.431	35.392	14.957	-26.251	35.623	-0.055	0.180	0.231	0.298	0.180
	34	19.721	-27.831	31.684	19.683	-27.658	31.853	-0.038	0.173	0.168	0.245	0.173
B PILLAR	35	-21.493	-32.021	9.660	-21.459	-31.648	9.620	0.034	0.373	-0.039	0.377	0.373
	36	-17.880	-31.974	9.779	-17.873	-31.665	9.759	0.006	0.310	-0.020	0.310	0.310
	37	-22.103	-31.063	18.022	-22.178	-30.721	18.090	-0.075	0.342	0.069	0.357	0.342
	38	-18.103	-31.016	18.080	-18.132	-30.709	18.170	-0.029	0.307	0.091	0.322	0.307
	39	-22.014	-29.764	27.024	-22.133	-29.460	27.162	-0.119	0.304	0.138	0.354	0.304
	40	-18.476	-29.635	27.322	-18.534	-29.351	27.429	-0.058	0.285	0.107	0.309	0.285

Note: Crush column is deformation perpendicular to the plane area of interest

Figure E-3. Occupant Compartment Deformation Data – Set 1, Test No. NJPCB-5

Date: 2/27/2018 Test Name: NJPCB-5 VIN: 1D3HB18P19S779289
Year: 2009 Make: Dodge Model: Ram

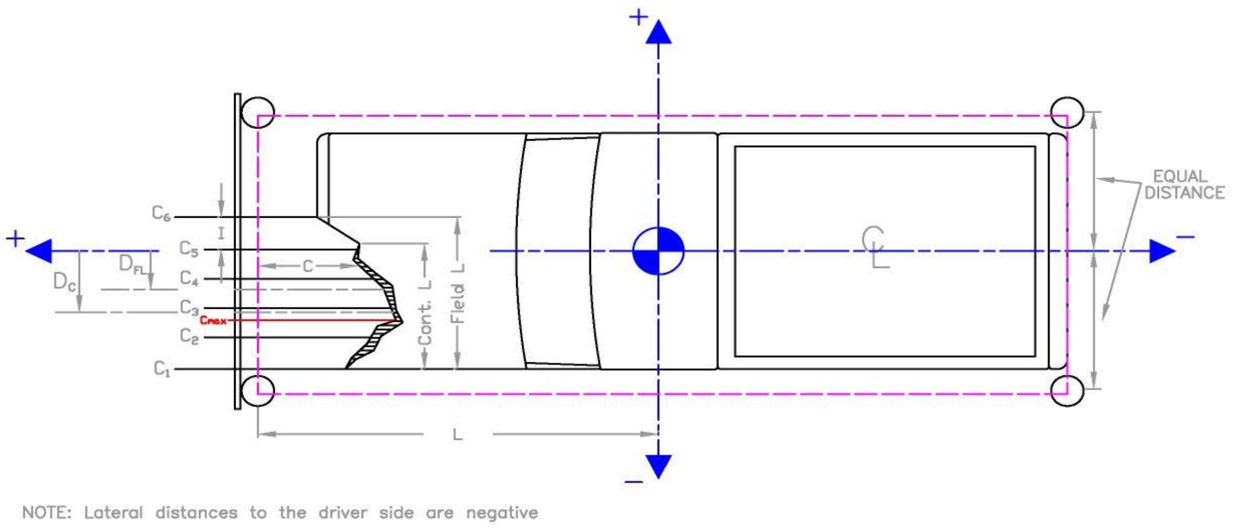
VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 2

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)	Crush (in.)
DASH	1	36.733	-30.465	25.628	36.475	-30.839	25.705	-0.258	-0.373	0.076	0.460	0.460
	2	34.822	-18.586	29.299	34.557	-18.915	29.361	-0.265	-0.330	0.062	0.428	0.428
	3	33.962	0.019	26.539	33.717	-0.272	26.524	-0.245	-0.290	-0.015	0.380	0.380
	4	34.188	-29.627	14.698	34.001	-29.941	14.740	-0.187	-0.314	0.042	0.368	0.368
	5	32.086	-18.961	15.082	31.959	-19.237	15.043	-0.126	-0.276	-0.039	0.306	0.306
	6	31.308	-0.061	14.701	31.239	-0.227	14.659	-0.068	-0.167	-0.042	0.185	0.185
SIDE PANEL	7	42.783	-32.709	5.252	42.669	-32.807	5.367	-0.114	-0.098	0.116	0.190	-0.098
	8	46.299	-32.869	4.607	46.135	-32.969	4.768	-0.164	-0.099	0.162	0.251	-0.099
	9	44.489	-32.721	1.466	44.510	-32.787	1.611	0.021	-0.066	0.145	0.161	-0.066
IMPACT SIDE DOOR	10	7.662	-33.832	23.233	7.454	-34.814	23.141	-0.208	-0.982	-0.092	1.007	-0.982
	11	18.717	-33.839	23.083	18.476	-34.644	23.078	-0.241	-0.805	-0.005	0.840	-0.805
	12	31.573	-33.839	22.721	31.358	-34.426	22.764	-0.215	-0.588	0.043	0.627	-0.588
	13	10.553	-34.620	10.527	10.318	-35.097	10.521	-0.235	-0.477	-0.006	0.532	-0.477
	14	22.332	-35.599	9.713	22.109	-35.936	9.660	-0.223	-0.338	-0.053	0.408	-0.338
	15	33.534	-34.149	9.259	33.252	-34.309	9.327	-0.282	-0.160	0.069	0.331	-0.160
ROOF	16	25.088	-25.826	42.113	24.769	-26.218	42.123	-0.319	-0.392	0.010	0.506	0.010
	17	27.248	-19.652	42.405	26.976	-20.088	42.431	-0.272	-0.436	0.026	0.514	0.026
	18	28.623	-14.081	42.523	28.403	-14.491	42.575	-0.220	-0.410	0.052	0.469	0.052
	19	29.501	-7.685	42.672	29.240	-8.032	42.803	-0.260	-0.347	0.131	0.453	0.131
	20	30.097	-0.023	42.639	29.852	-0.371	42.813	-0.246	-0.348	0.174	0.460	0.174
	21	18.701	-23.524	45.180	18.376	-23.840	45.190	-0.325	-0.316	0.010	0.453	0.010
	22	19.816	-18.215	45.534	19.522	-18.590	45.564	-0.294	-0.375	0.031	0.478	0.031
	23	20.553	-13.102	45.751	20.249	-13.499	45.813	-0.305	-0.397	0.062	0.504	0.062
	24	21.389	-7.386	45.842	21.070	-7.663	45.946	-0.319	-0.277	0.104	0.435	0.104
	25	21.558	-0.468	45.909	21.296	-0.837	46.036	-0.262	-0.369	0.128	0.470	0.128
	26	13.981	-22.905	45.862	13.706	-23.207	45.847	-0.275	-0.301	-0.015	0.408	-0.015
	27	14.798	-17.971	46.197	14.493	-18.326	46.208	-0.305	-0.355	0.011	0.469	0.011
	28	15.605	-12.941	46.399	15.381	-13.250	46.435	-0.224	-0.310	0.035	0.384	0.035
	29	17.090	-7.181	46.442	16.807	-7.538	46.518	-0.283	-0.357	0.075	0.461	0.075
	30	17.881	-0.691	46.427	17.652	-0.971	46.534	-0.229	-0.280	0.107	0.377	0.107
A PILLAR	31	25.549	-27.353	40.653	25.280	-27.702	40.630	-0.269	-0.350	-0.023	0.442	-0.350
	32	29.409	-28.335	38.595	29.140	-28.689	38.623	-0.269	-0.354	0.028	0.445	-0.354
	33	35.935	-29.920	34.438	35.672	-30.275	34.430	-0.262	-0.355	-0.008	0.441	-0.355
	34	40.722	-31.050	30.710	40.440	-31.408	30.764	-0.282	-0.357	0.054	0.458	-0.357
B PILLAR	35	0.080	-32.149	7.173	-0.026	-32.023	7.106	-0.107	0.126	-0.067	0.178	0.126
	36	3.678	-32.194	7.419	3.583	-32.149	7.242	-0.095	0.045	-0.177	0.207	0.045
	37	-0.817	-31.988	15.653	-0.944	-31.957	15.482	-0.127	0.031	-0.171	0.215	0.031
	38	3.187	-32.041	15.780	3.044	-32.057	15.659	-0.143	-0.016	-0.121	0.188	-0.016
	39	-0.980	-31.562	24.787	-1.162	-31.640	24.609	-0.183	-0.077	-0.177	0.266	-0.077
	40	2.604	-31.541	25.207	2.398	-31.648	25.022	-0.206	-0.107	-0.185	0.297	-0.107

Note: Crush column is deformation perpendicular to the plane area of interest

Figure E-4. Occupant Compartment Deformation Data – Set 2, Test No. NJPCB-5

Date:	2/8/2017	Test Name:	NJPCB-5	VIN:	1D3HB18P19S779289
Year:	2009	Make:	Dodge	Model:	Ram



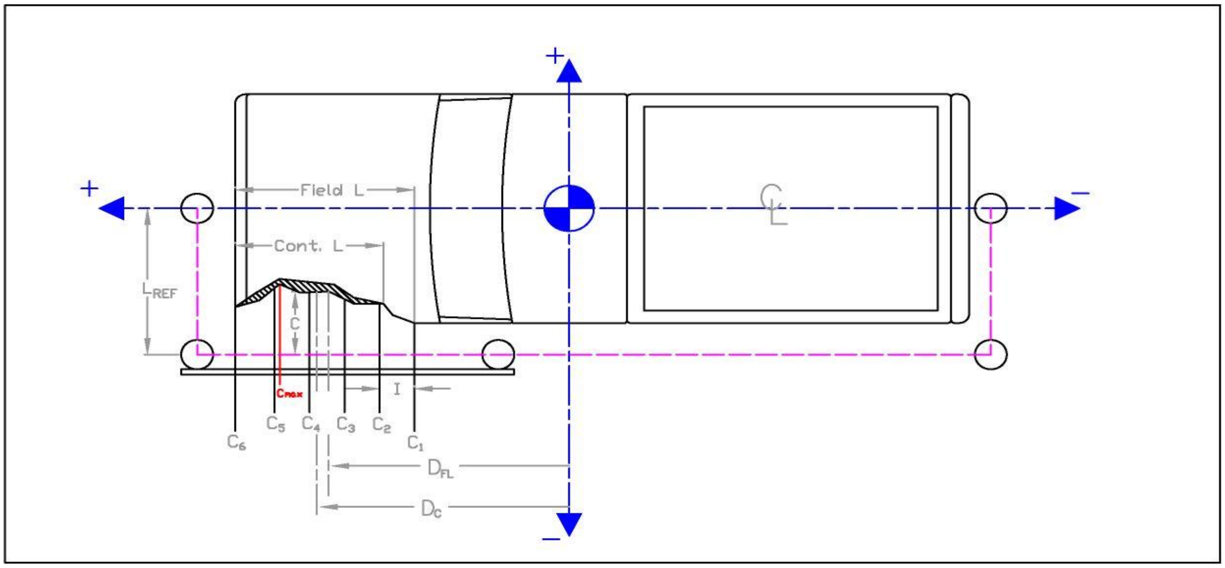
	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	105 1/2	(2680)
Total Vehicle Width:	76 7/8	(1953)
Width of contact and induced crush - Field L:	43 1/2	(1105)
Crush measurement spacing interval (L/5) - I:	8 3/4	(222)
Distance from center of vehicle to center of Field L - D_{FL}:	-16 3/4	-(425)
Width of Contact Damage:	20 1/2	(521)
Distance from center of vehicle to center of contact damage - D_C:	-28 1/8	-(714)

NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., side of vehicle has been pushed inward)
NOTE: All values must be filled out above before crush measurements are filled out.

	Crush Measurement		Lateral Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual Crush	
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	na	NA	-38 1/2	-(978)	22 1/2	(572)	- 2/3	-(17)	NA	NA
C_2	24 1/2	(622)	-29 3/4	-(756)	9 1/8	(232)			16	(408)
C_3	7 3/4	(197)	-21	-(533)	5 7/8	(149)			2 4/7	(65)
C_4	2 1/2	(64)	-12 1/4	-(311)	4 5/8	(117)			-1 4/9	-(37)
C_5	2 1/2	(64)	-3 1/2	-(89)	4	(102)			- 4/5	-(21)
C_6	3	(76)	5 1/4	(133)	4 1/8	(105)			- 4/9	-(11)
C_{MAX}	26	(660)	29	(737)	8 5/8	(219)			18	(459)

Figure E-5. Exterior Vehicle Crush (NASS) - Front, Test No. NJPCB-5

Date:	**2/8/2017**	**Test Name:**	**NJPCB-5**	**VIN:**	**1D3HB18P19S779289**
Year:	**2009**	**Make:**	**Dodge**	**Model:**	**Ram**



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	**48 1/2**	**(1232)**
Total Vehicle Length:	**229 1/4**	**(5823)**
Distance from vehicle c.g. to 1/2 of Vehicle total length:	**-13 1/5**	**-(335)**
Width of contact and induced crush - Field L:	**229 1/4**	**(5823)**
Crush measurement spacing interval (L/5) - I:	**45 7/8**	**(1165)**
Distance from vehicle c.g. to center of Field L - D_{FL}:	**-13 1/5**	**-(335)**
Width of Contact Damage:	**229 1/4**	**(5823)**
Distance from vehicle c.g. to center of contact damage - D_C:	**-13 1/5**	**-(335)**

NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., front of vehicle has been pushed inward or tire has been removed)
NOTE: All values must be filled out above before crush measurements are filled out.

	Crush Measurement		Longitudinal Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual	Crush
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	NA	NA	-127 7/8	-(3248)	33 1/2	(851)	4 1/2	(114)	NA	NA
C_2	23 1/4	(591)	-82	-(2083)	5 1/4	(133)			13 1/2	(343)
C_3	8 3/4	(222)	-36 1/8	-(918)	5 5/8	(143)			-1 3/8	-(35)
C_4	7 1/2	(191)	9 3/4	(248)	5 1/8	(130)			-2 1/8	-(54)
C_5	14 1/4	(362)	55 5/8	(1413)	5	(127)			4 3/4	(121)
C_6	32 1/4	(819)	101 1/2	(2578)	33 1/2	(851)			-5 3/4	-(146)
C_{MAX}	24 1/2	(622)	72	(1829)	5 1/8	(130)			14 7/8	(378)

Figure E-6. Exterior Vehicle Crush (NASS) - Side, Test No. NJPCB-5

Appendix F. Accelerometer and Rate Transducer Data Plots, Test No. NJPCB-5

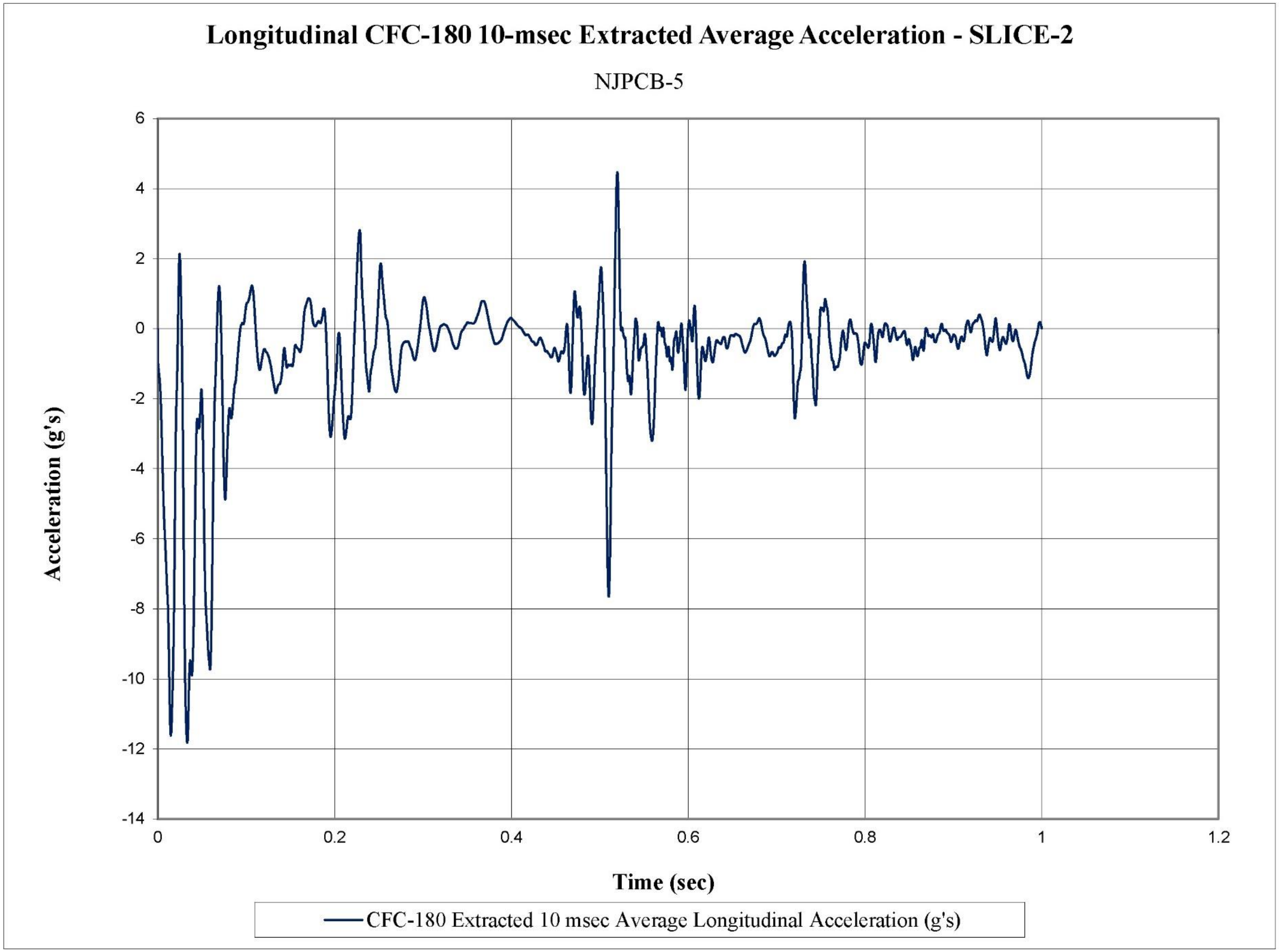


Figure F-1. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. NJPCB-5

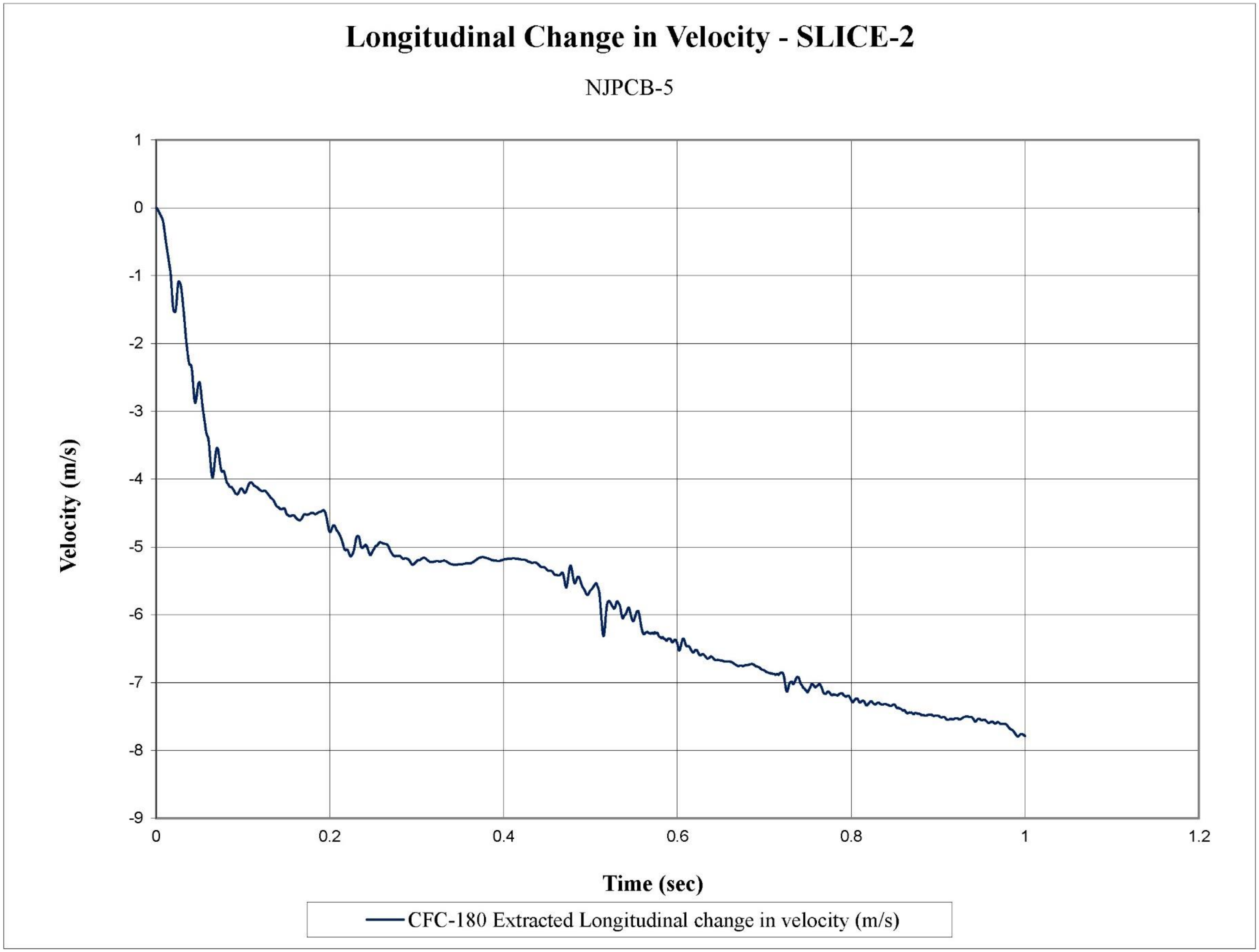


Figure F-2. Longitudinal Occupant Impact Velocity (SLICE-2), Test No. NJPCB-5

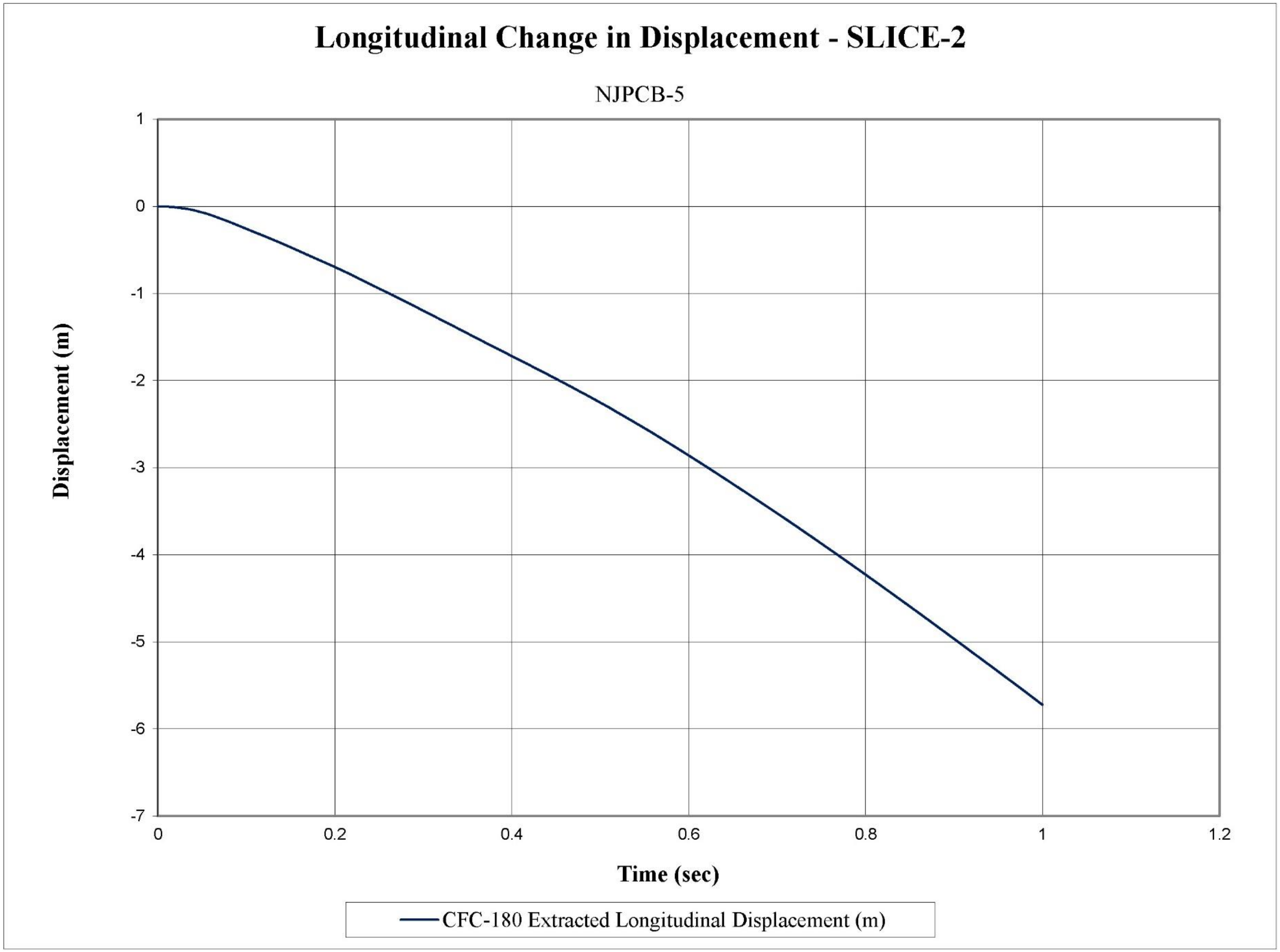


Figure F-3. Longitudinal Occupant Displacement (SLICE-2), Test No. NJPCB-5

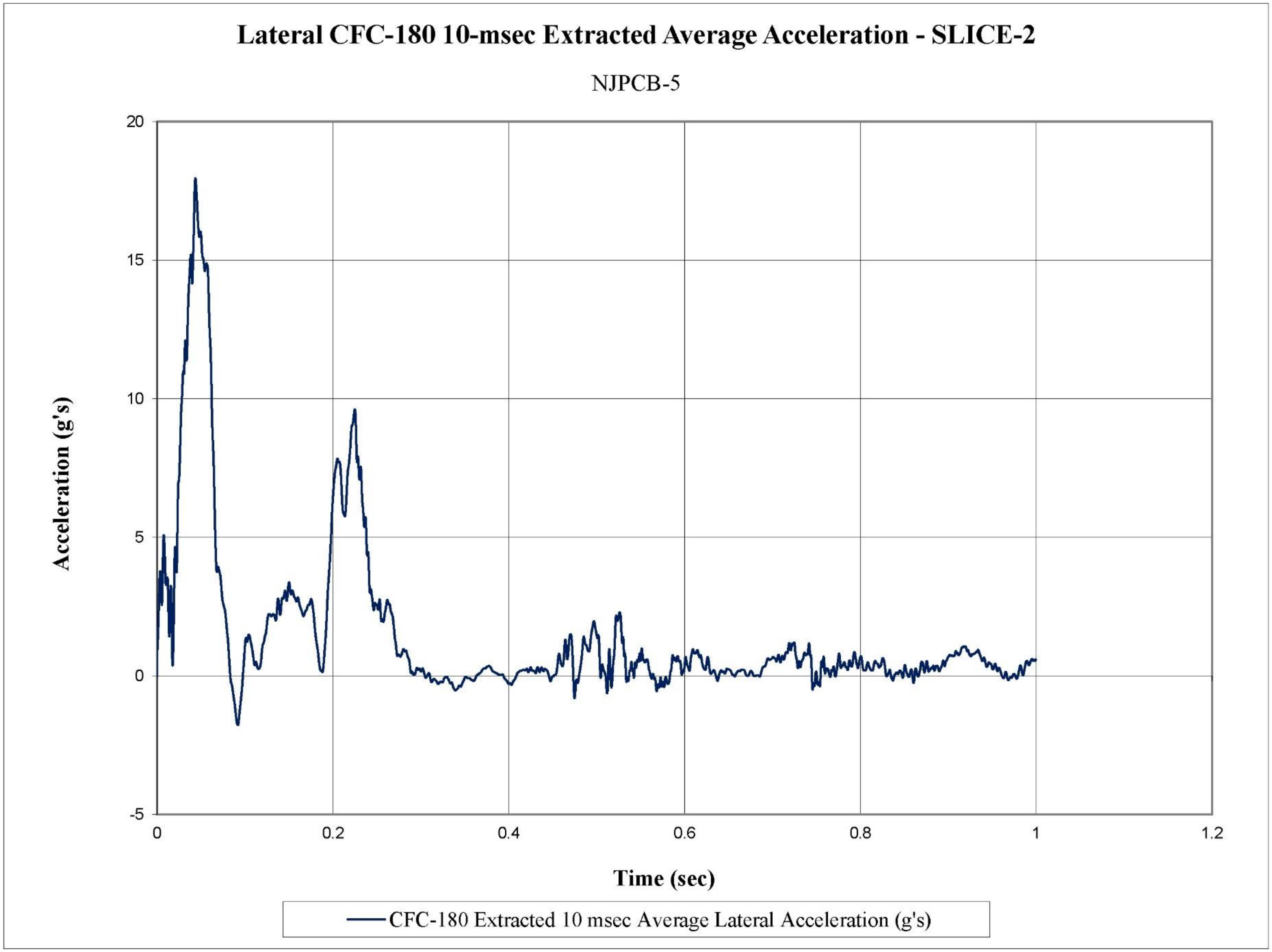


Figure F-4. 10-ms Average Lateral Deceleration (SLICE-2), Test No. NJPCB-5

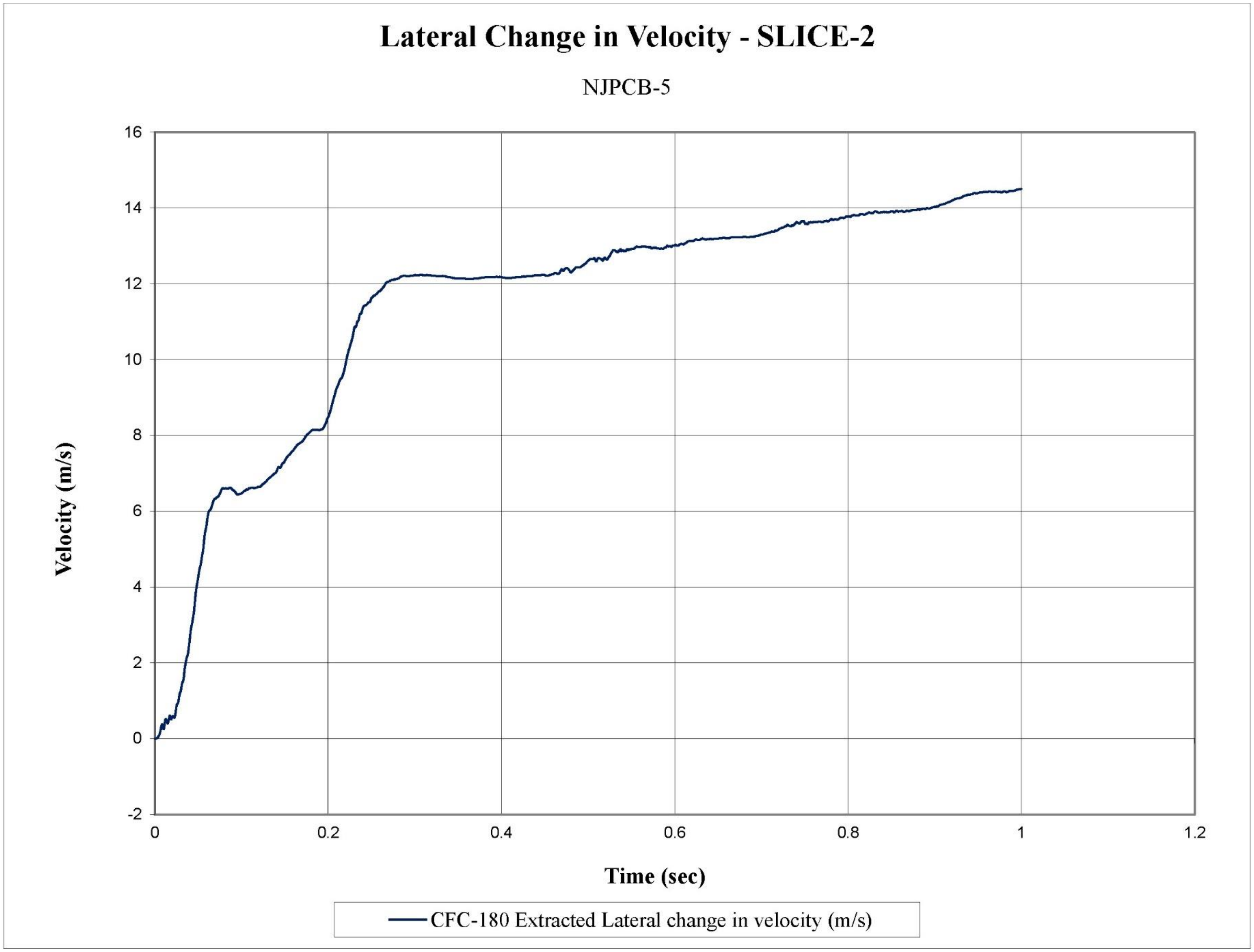


Figure F-5. Lateral Occupant Impact Velocity (SLICE-2), Test No. NJPCB-5

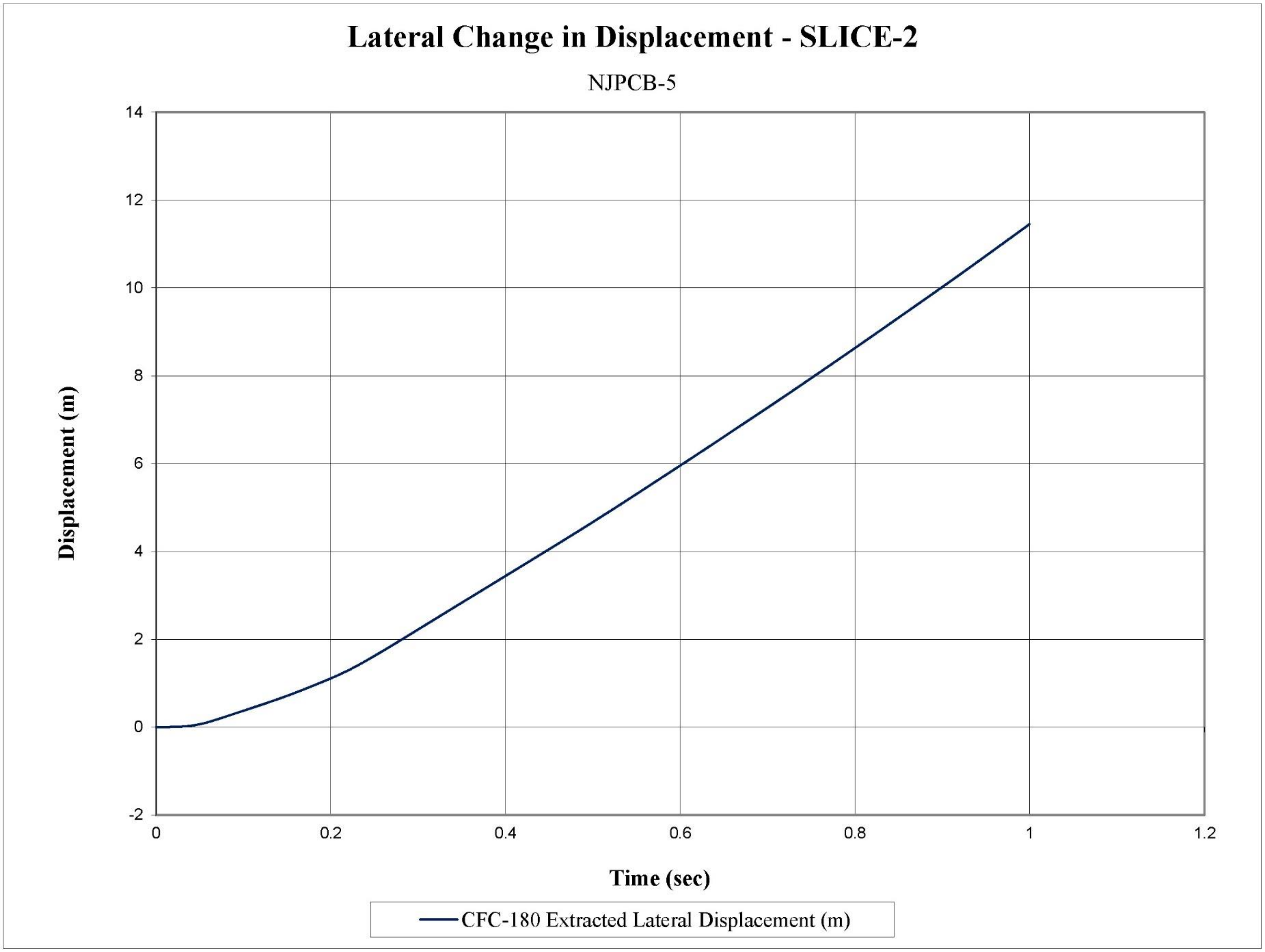


Figure F-6. Lateral Occupant Displacement (SLICE-2), Test No. NJPCB-5

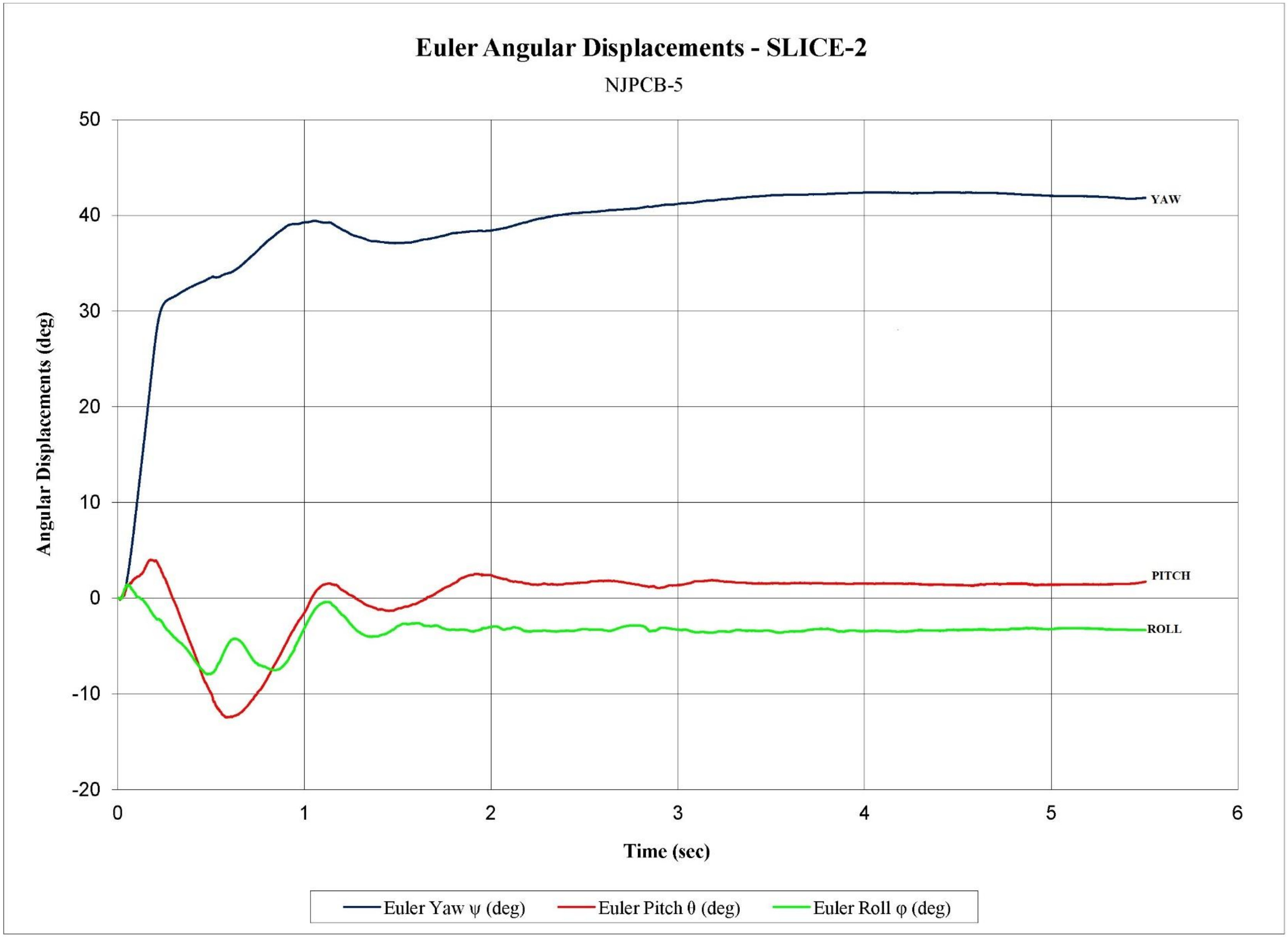


Figure F-7. Vehicle Angular Displacements (SLICE-2), Test No. NJPCB-5

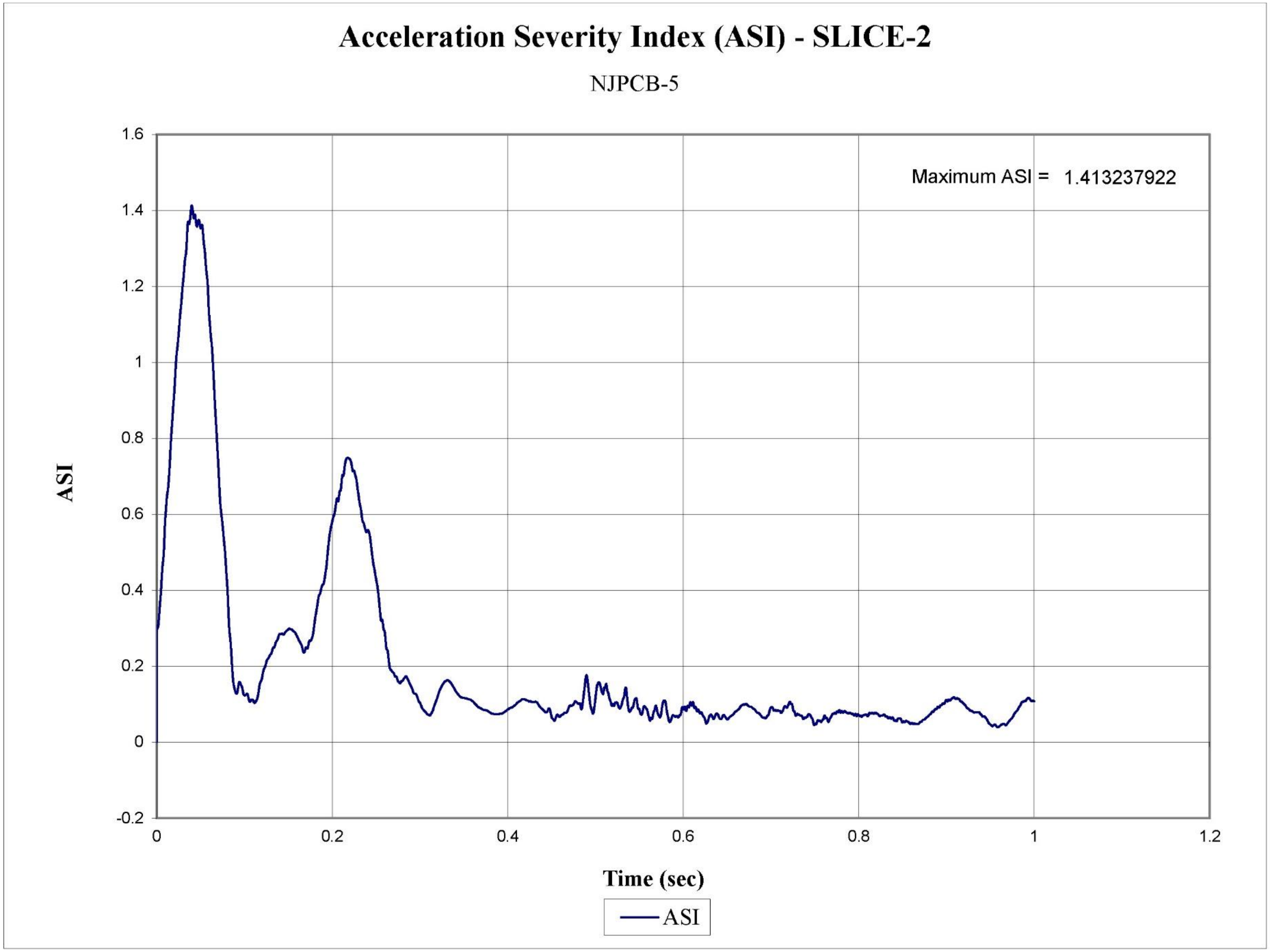


Figure F-8. Acceleration Severity Index (SLICE-2), Test No. NJPCB-5

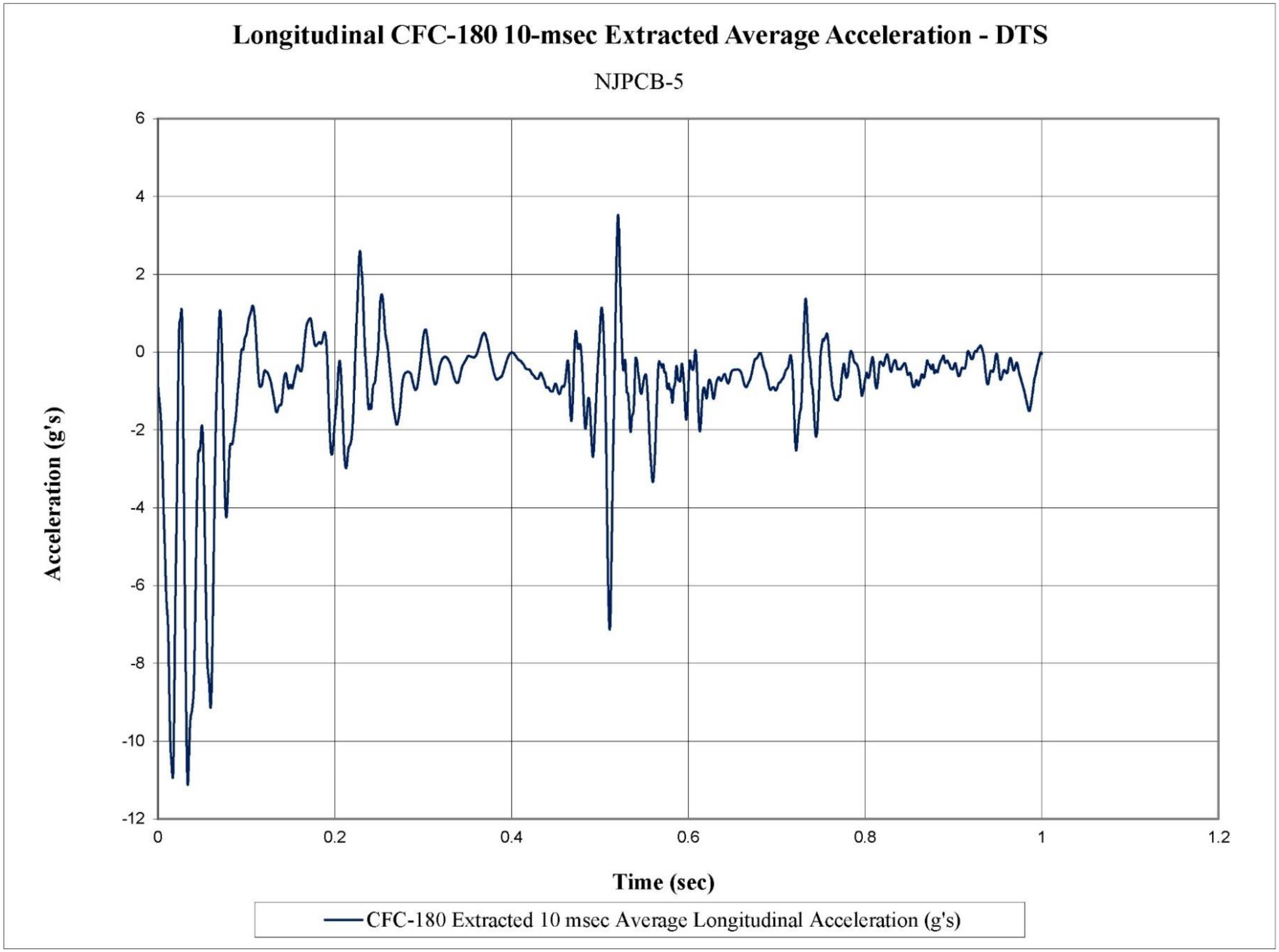


Figure F-9. 10-ms Average Longitudinal Deceleration (DTS), Test No. NJPCB-5

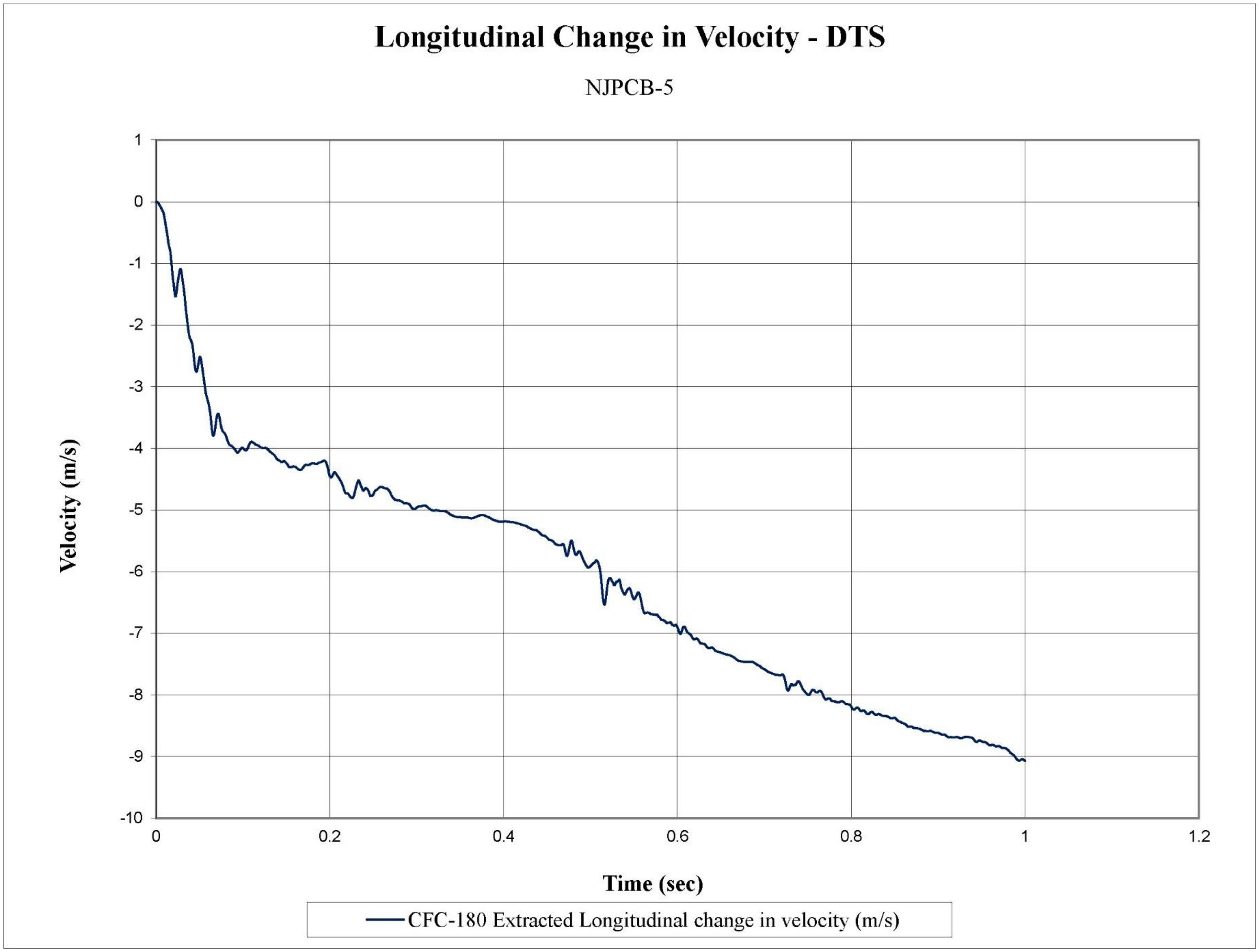


Figure F-10. Longitudinal Occupant Impact Velocity (DTS), Test No. NJPCB-5

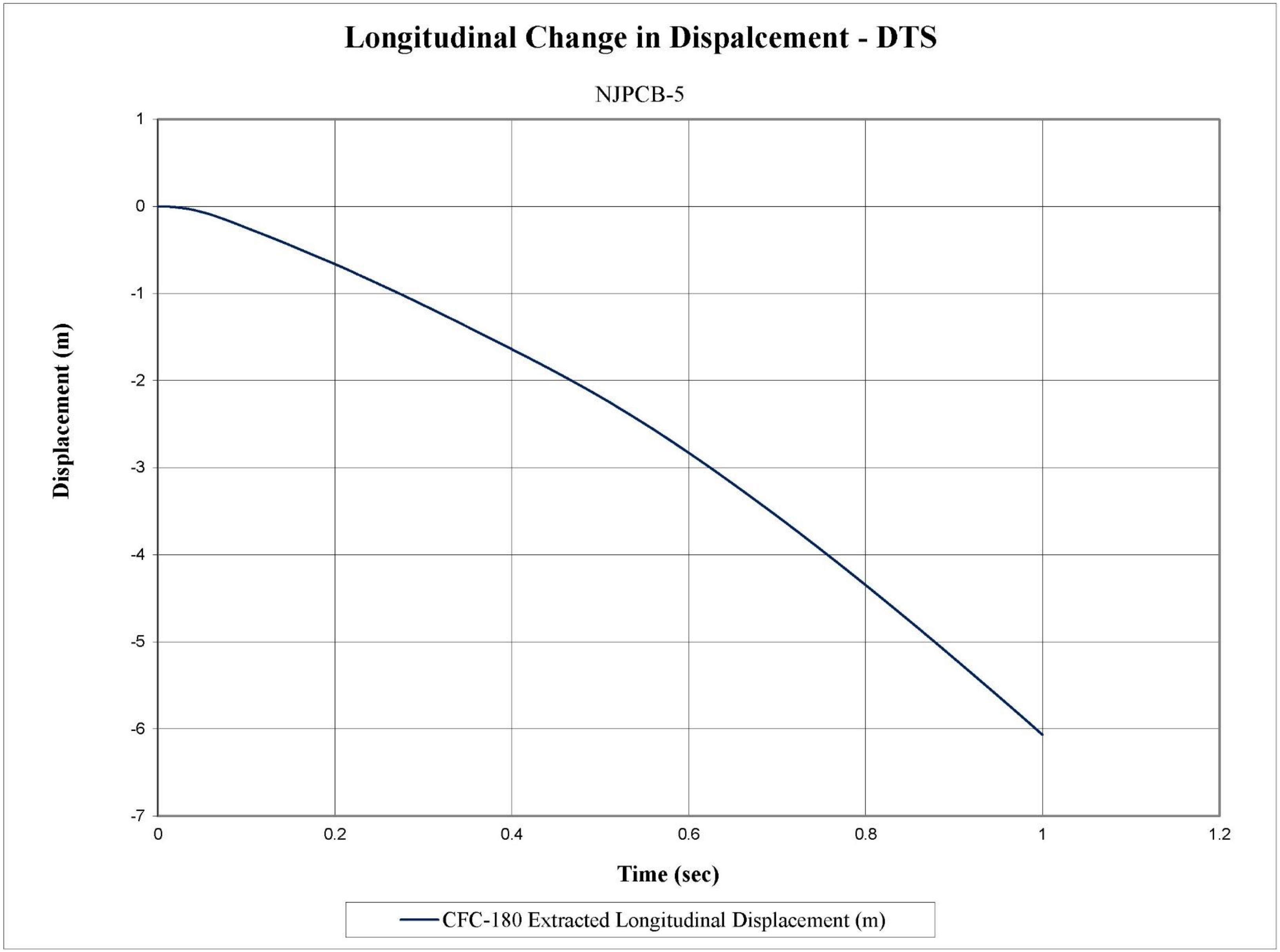


Figure F-11. Longitudinal Occupant Displacement (DTS), Test No. NJPCB-5

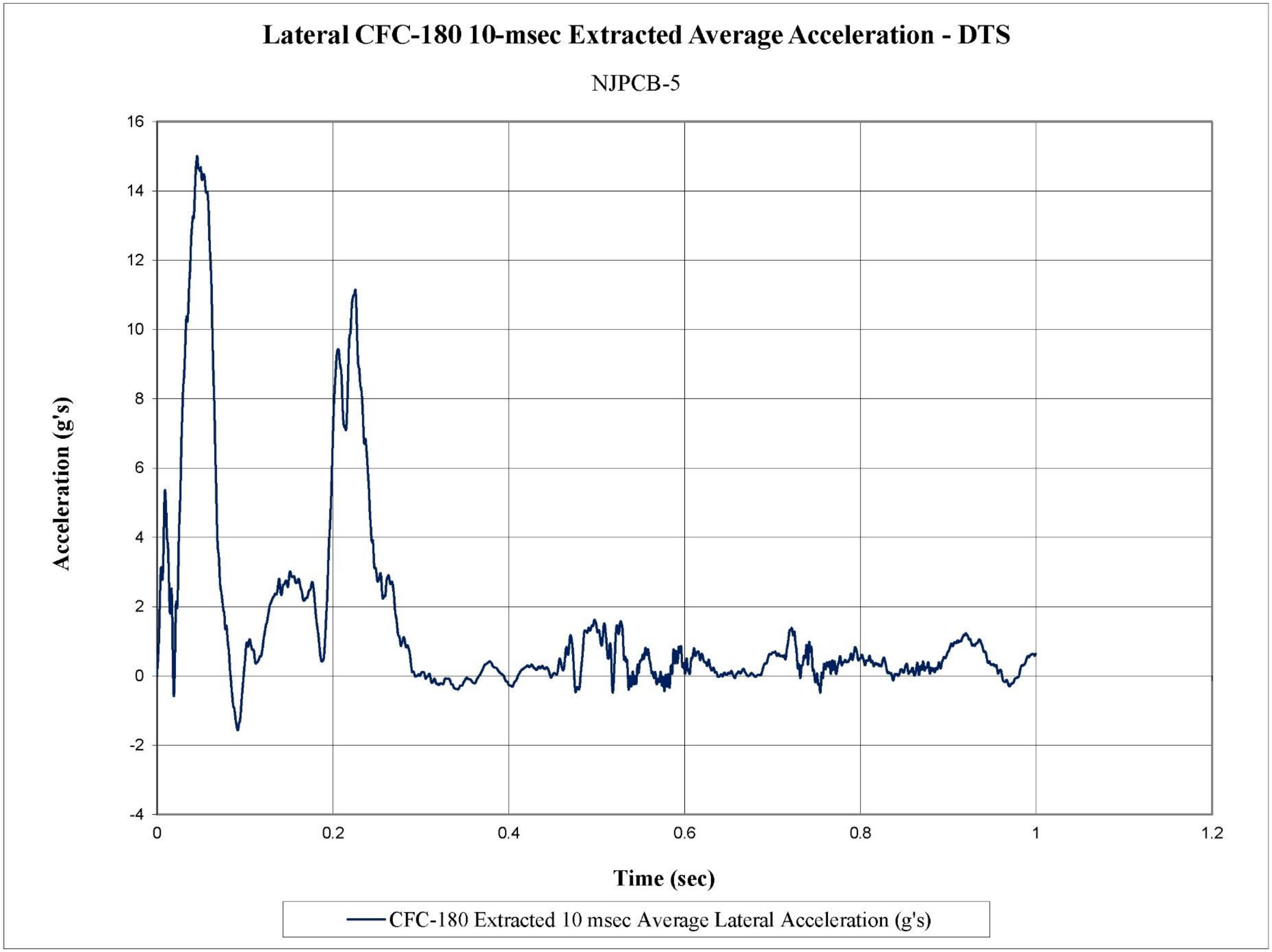


Figure F-12. 10-ms Average Lateral Deceleration (DTS), Test No. NJPCB-5

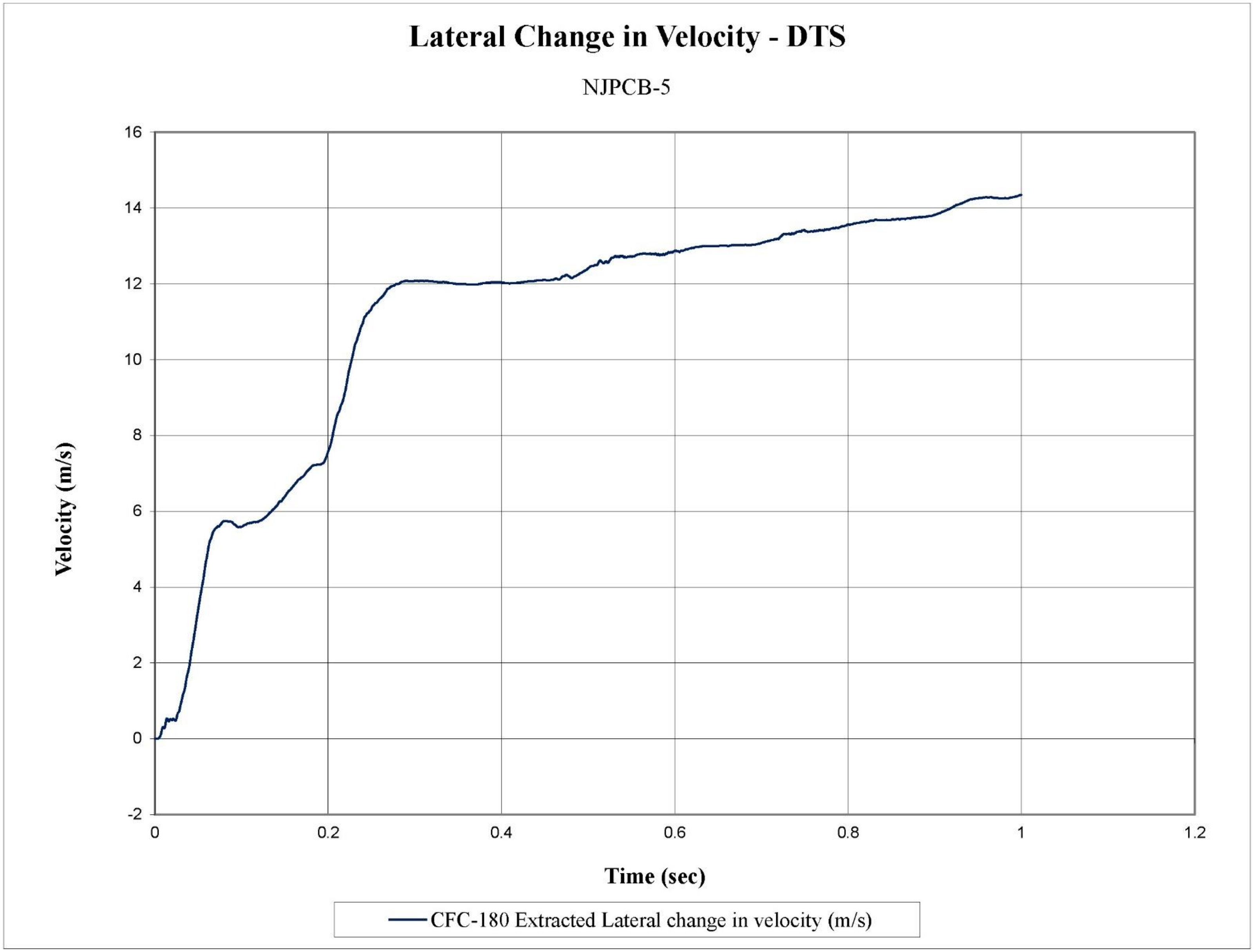


Figure F-13. Lateral Occupant Impact Velocity (DTS), Test No. NJPCB-5

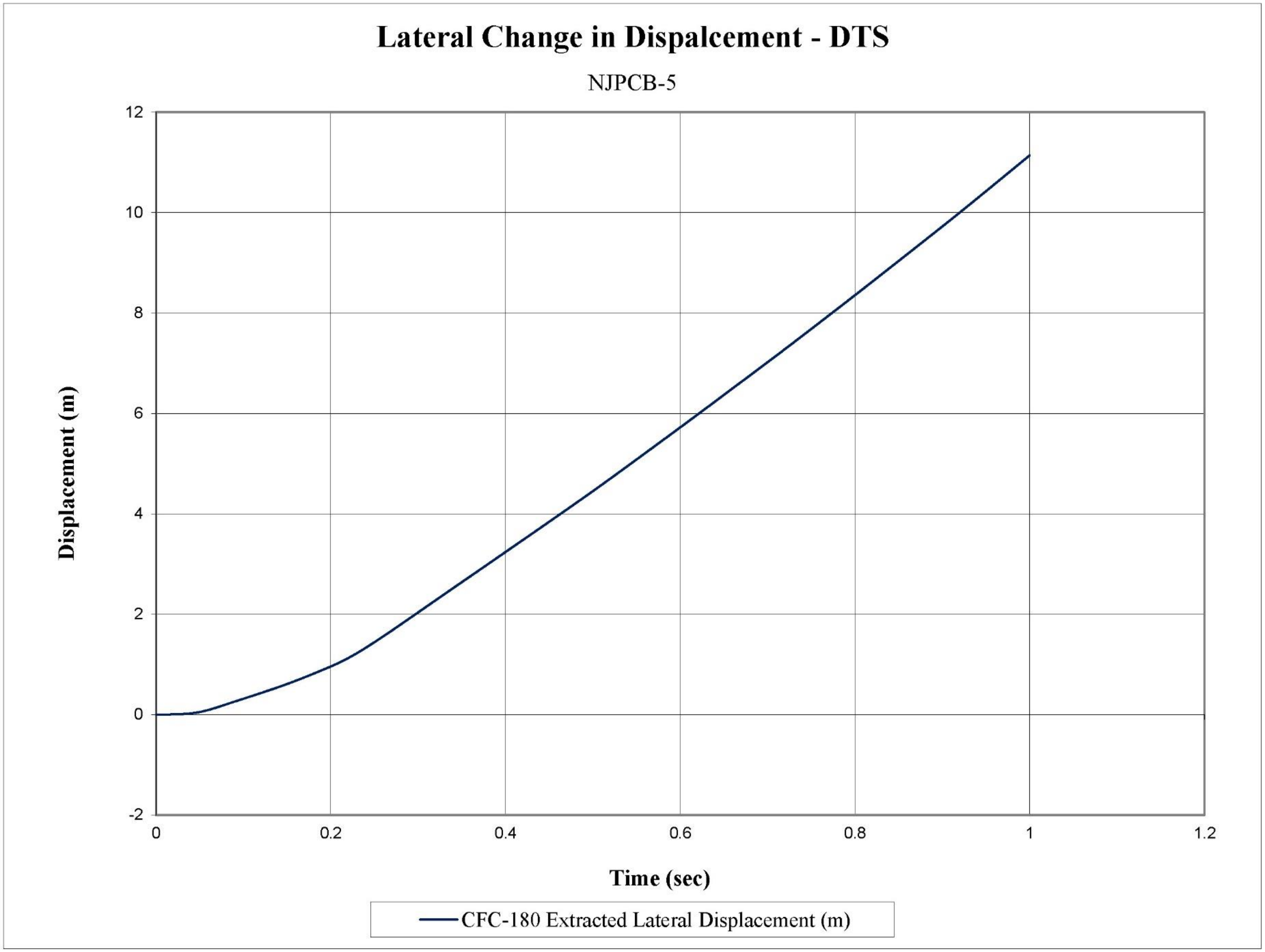


Figure F-14. Lateral Occupant Displacement (DTS), Test No. NJPCB-5

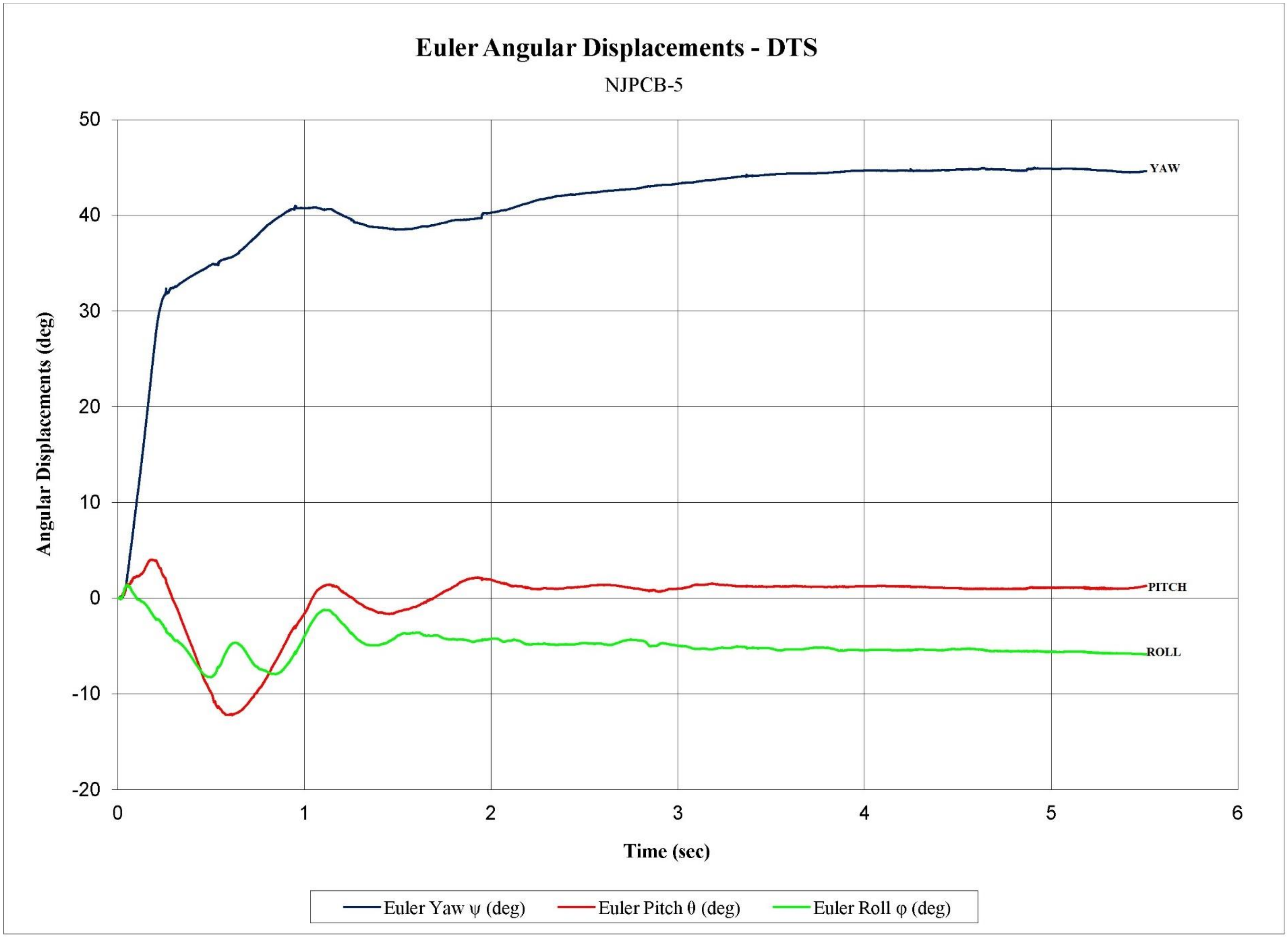


Figure F-15. Vehicle Angular Displacements (DTS), Test No. NJPCB-5

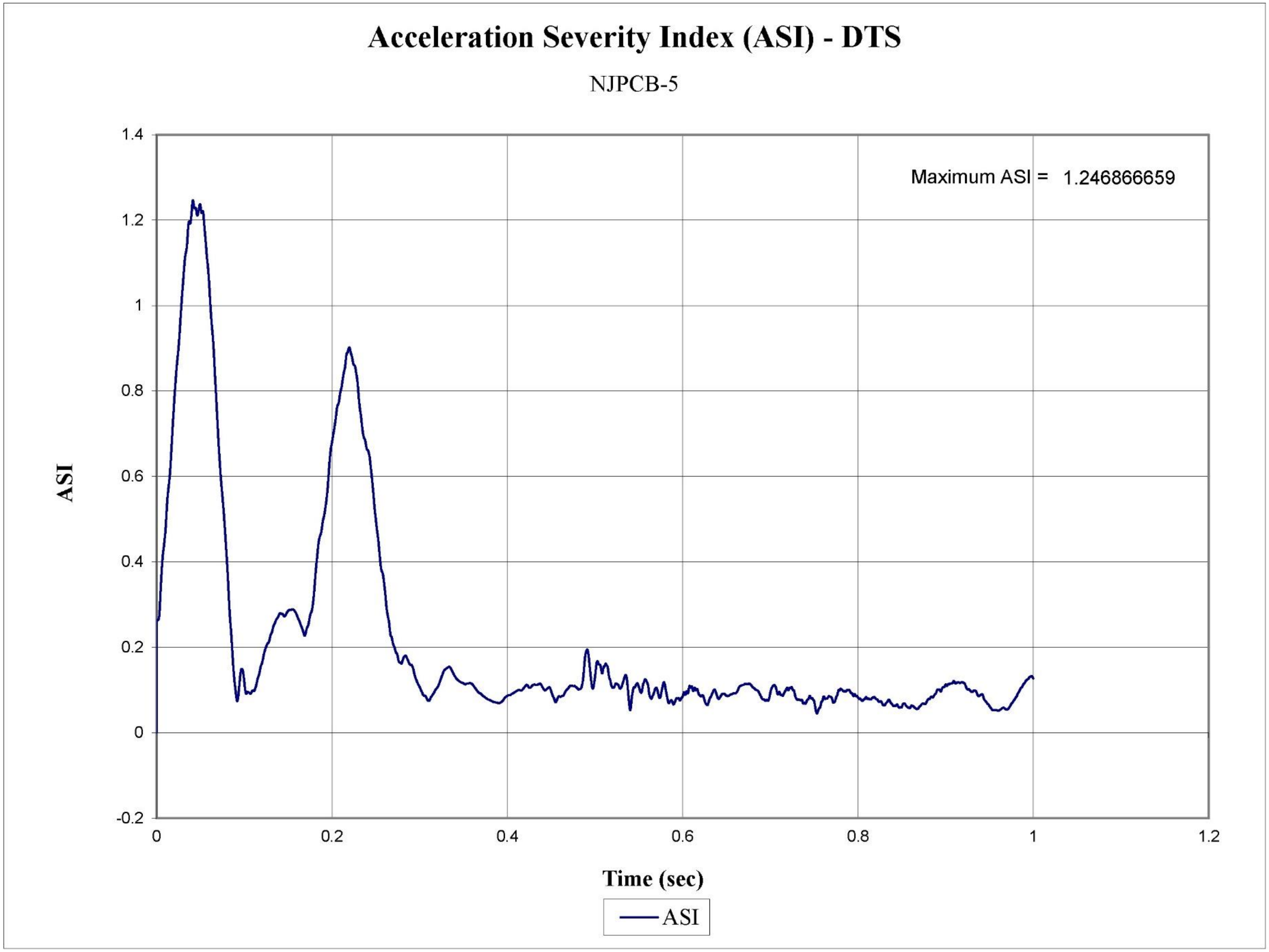


Figure F-16. Acceleration Severity Index (DTS), Test No. NJPCB-5

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